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The Magnetic Pole, A Useless Concept

F. W. WARBURTON, *Department of Physics, University of Kentucky*

The description of magnetism in terms of moving electric charges rather than in terms of magnetic poles reduces both the number of experimental laws upon which the theory is based and the number of new quantities defined. Certain sources of confusion are discussed and an elementary description is developed which permits a clearer visualization of the process of magnetization than does the pole theory and which is, in certain respects, less confusing. Emphasis is placed on the distinctions between the electric fields, E and D, and the magnetic fields, B and H, and their relative importance. The definitions are chosen so as to give each of these four quantities simple physical meaning.

THE magnetic pole, as an entity, as a unit of magnetism from which 4π "lines of force" emanate, is showing signs of vanishing from the theory of electricity and magnetism. No free poles have ever been found. Swann[1] some years ago classed the pole as obnoxious and unnecessary and Mason and Weaver[2] consider it non-existent. The most accurate determinations of magnetic quantities are now made in terms of magnetic forces of currents.[3] In most textbooks, however, the pole still clings tenaciously to a place of fundamental importance. It appears as the new and as the all-important quantity in Coulomb's law of attraction and repulsion of poles, upon which the theory of magnetism is based. When the magnetic field strength is defined as the force on a pole, it is inevitable that the student accept the pole as very fundamental and he can give up the pole later only with considerable reluctance and confusion. Developing a subject in historical order has advantages but when such development fixes in the mind of the student that the pole, which is non-existent, is the fundamental quantity of magnetism, the method loses its value. This fiction is avoidable and it seems opportune that an improvement of presentation should filter down into intermediate and elementary teaching.

In this paper an endeavor is made to show that an elementary description of magnetic phenomena entirely in terms of currents composed of moving electrons can be made more simple and less confusing than the discussions involving poles. Instead of three laws, (*a*) Coulomb's law for charges, (*b*) the corresponding expression for magnetic poles and (*c*) the interaction of poles and currents, we can have two fundamental expressions: (*a*) Coulomb's law for charges and (*b*) the corresponding law for the magnetic effect of moving charges, Eq. (8), while the properties of magnetic substances can be expressed in terms of current whirls. This procedure treats magnetism with the introduc-

[1] Swann, *Bulletin of the National Research Council* **4**, Part 6, No. 24, 12, Dec., 1922.

[2] Mason and Weaver, *The Electromagnetic Field*, University of Chicago Press, 1929.

[3] In his address before the American Physical Society at Chicago in June, 1933, Dr. H. L. Curtis stated that the ampere is now determined most accurately by means of the current balance.

tion of no new quantities. The Gaussian system of units is used throughout.[4]

The first difficulty with the pole theory appears in Coulomb's law itself. As usually expressed, the law, $f=mm'/\mu r^2$, implies that the poles are permanent quantities unchanged by the introduction of magnetic material of permeability μ and it states clearly that the force of attraction between the "north" end of a long magnet and the nearby "south" end of another long magnet is decreased upon the introduction of soft iron ($\mu>1$) between them. This is contrary to fact and, rather than consider a revision of the law, one usually employs devious explanations in this, the most evident case of the effect of the magnetic medium. Why resort to consideration of the "induced" poles in the soft iron, when the permeability is introduced expressly for the purpose of describing the behavior of the medium?

The "demagnetizing effect of the induced poles" is another source of difficulty. The student learns to believe that by the use of the "demagnetizing field" he has explained quite simply the experimental fact that the so-called "magnetic induction" B, in a short piece of a given specimen of soft iron in a given field H, is much less than B in a long piece in the same field H. Yet when he attempts to follow out his explanation more in detail, his induced poles fade away and he is forced to consider the interaction between the atoms. Indeed, when one expresses the magnetic moment of the atom in terms of Amperian currents and motions of electrons, he has no language in which to describe the imaginary stuff at the ends of the iron, and such a demagnetizing field does not exist. All the atoms in the iron may be divided into two classes: those whose fields at the point in question oppose the applied field H and those whose fields have components in the direction of the applied field. Letting A (Fig. 1) be the point at which the field is desired, and letting C be an atom whose field at A is normal to H, we can see that

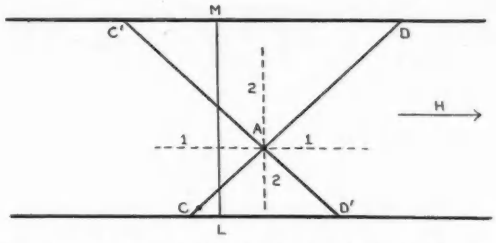

FIG. 1. Atoms in regions 2 contribute a demagnetizing field at A and those in regions 1, a self-magnetizing field.

the surfaces, of which CD and $C'D'$ are traces, containing all the atoms C, divide the iron into two parts. In regions 2 the atoms contribute a demagnetizing field at A and in regions 1 the atoms contribute a partial field in the direction of H, the self-magnetizing field. One should not consider the demagnetizing field (regions 2) without at the same time considering the self-magnetizing field (regions 1). If the iron be cut in two at LM and the left end removed so that A is near the end, we see that the field at A is reduced, not because of a demagnetizing field but because of a reduced region 1 supplying a self-magnetizing field. In a short piece of a paramagnetic material, in which there is no appreciable interaction between the atoms, the field B should be less than in the long piece, simply because there are not so many atoms of the material contributing to B. These two causes, the fields of neighboring atoms together with the effect of the number of atoms, are ample to describe qualitatively the experimental facts in iron. The foregoing demagnetizing and self-magnetizing fields are effects of the applied field H as well as causes of B. B is always the combined effect of the applied field H and the contribution of the atomic orbital currents. It is customary to designate a field H' within the iron which is the combined effect of the applied field H and the usual "demagnetizing" field. This classical "magnetic field within iron," H', serves no useful purpose. The numerical difference between B and H is the contribution of the magnetic material. The permeability μ, introduced as the factor describing the medium, should represent the fractional increase of field upon addition of the magnetic medium; hence H inside the iron should be the applied field alone. This means that the ratio B/H in the short piece of iron

[4] Since, in electrostatics, the Gaussian system is identical with the electrostatic system and, in the case of magnetic quantities, identical with the electromagnetic system, it can readily be used in elementary teaching. At the same time it is equally as satisfactory in theoretical developments as the other rational system.

differs from that in the long piece and also varies from point to point in iron which is non-uniformly magnetized. For quantitative computations, rather than use tables of "demagnetization factors" for correction for H', we should use the corresponding tables for B.

The elimination of the "demagnetizing field of the induced poles" is in harmony with the useful approximate relation between flux, magnetomotive force and reluctance in the magnetic circuit. Such a circuit is composed of comparatively short lengths of magnetic media of different permeabilities, yet it has been customary here not to introduce the "demagnetizing" fields but rather to consider "ampere turns" as the sole cause of magnetization, and to add the correction in terms of flux leakage.

Electrostatics

The electric field, defined as the force on a charge, $E=f/q'$, takes within a parallel plate condenser the form,

$$E=4\pi\sigma, \tag{1}$$

where σ is the surface density of charge on either plate. When a dielectric material is introduced between the plates of the condenser, the charge q being maintained on the plates, it is convenient to compare the (weaker) field E in the dielectric medium with the field which was there with the same charge q in vacuum. The latter field is the so-called "electric induction" D,

$$D=4\pi\sigma. \tag{1a}$$

Each electron of the medium experiences a force directed toward the positive plate equal to $E\times 4.77\times 10^{-10}$ dynes. The resulting displacement of the electron depends on this force and on the atomic restoring forces. The displaced electron together with the equal positively charged atom constitutes a dipole. The electric moment of the dipole may be defined either as the product of the charge and its displacement, or as the ratio of the maximum torque on a rigid dipole to the field E,

$$es=L_{\max}/E. \tag{2}$$

The electric moment of an atom is the sum of the products of the charge on each electron and its displacement. The sum of the electric moments of all the atoms divided by the volume is a quantity which is a measure of the state of the dielectric medium and is called the polarization P,

$$P=\Sigma es/v. \tag{3}$$

Polarization is a volume effect; it is a shift in position of electrons throughout the material. In any cubic centimeter within the material there are as many negative charges as positive charges, while there is a surface charge of negative electricity at the boundary of the dielectric medium near the positive plate and a positive charge at the negative plate. In order to see that the surface density of this charge is equal to P, we have only to observe that $q_p l$, the product of this charge and the distance l between q_p and $-q_p$, is equal to the total electric moment, Σes. Solving for q_p and dividing by the area, we see that the surface density of the induced charge is $q_p/A=\Sigma es/Al=\Sigma es/v=P$, the polarization. The net charge at the plates is thus reduced from q to $q-q_p$, q remaining constant, and the net surface density of charge is $\sigma-P$; hence the field is reduced from

$$D=4\pi\sigma \tag{1a}$$

to

$$E=4\pi(\sigma-P); \tag{4}$$

thus

$$E=D-4\pi P. \tag{5}$$

The potential difference between the plates is given by

$$V=W/q'=\int Eds, \tag{6}$$

and in vacuum $V_0=\int Dds$.

With constant q,

$$\sigma/(\sigma-P)=q/(q-q_p)=D/E=V_0/V=C/C_0=\epsilon, \tag{7}$$

where C and C_0 are the capacitances of the condenser with and without the dielectric. The dielectric constant ϵ is an indicator of the effect of the medium. It gives the field E within the medium for any applied field D.

In many cases of practical importance the potential difference between the plates of the condenser, rather than the charge q, is kept constant or externally controlled, when the dielectric medium is introduced. The charge on the plates q_0 then increases to q until the field E is equal to the original field E_0. Hence

$$E_0=4\pi\sigma_0,$$

$$E=E_0=4\pi(\sigma-P),$$

and therefore $\sigma=\sigma_0+P$, while $D=4\pi\sigma$ and $E=D-4\pi P$ as before. Thus

$$\sigma/\sigma_0=q/q_0=D/E=C/C_0=\epsilon. \tag{7a}$$

Since, in practice, electric fields are usually set up between charges on metallic conductors the potentials of which are externally controlled, it is V and E which are of physical importance. Were the charge q externally controlled, D and V_0 would assume greater importance. In both cases D is the field due to the "free" charge q, whereas E is the field due to the combined effect of q and the induced charge q_p.

Magnetostatics

Magnetism is an effect of moving charges. Two currents i and i' exhibit an attraction when flowing in the same direction and a repulsion when flowing in the opposite direction. These magnetic forces are proportional to the magnitudes of the currents i and i' and to their

lengths s and s' and vary inversely as the square of the distance between them; that is

$$f = kisi's'/c^2r^2, \tag{8}$$

provided s and s' are short compared to r and s' is a part of a closed circuit. The constant k is dimensionless, a function of the angles between i and i', i and r, i' and r. Eq. (8) is the fundamental "law" of magnetism. The justification for designating this expression as fundamental is that on it can be built the theory necessary for describing all phenomena of magnetostatics. If i is to be expressed in the (electrostatic) units used in Eqs. (1) to (7), c must have the dimension of a speed. Experimentally c is found to equal within the limits of error, the speed of light,[5] $c = 2.99796 \times 10^{10}$ cm·sec.$^{-1}$.

Since is and $i's'$ are directed quantities it is found convenient to use vector notation and to define the magnetic field as the region around one closed circuit made up of current elements $i's'$, in which another current element is experiences a force. The field strength H, in gauss, is equal in magnitude to the force in dynes acting on c electrostatic units of current (1 cgsm) 1 cm in length and its direction is given by the well-known right-hand rule. That is,

$$H = f/(is/c), \tag{9}$$

when i is perpendicular both to f and to H. The force on a wire carrying current making an angle α with the field H is, in view of Eq. (9), given by

$$f = H(i/c)s \sin \alpha. \tag{9a}$$

The force on a single charge moving with speed v perpendicular to a magnetic field is $f = Hqv/c$.

By combining Eq. (9a) with Eq. (8), the remaining part of k becomes $\sin \theta$, where θ is the angle between i' and r, and

$$H = \Sigma(i's'/cr^2) \sin \theta, \tag{10}$$

where the direction of H is given by the proper right-hand rule. This holds only when s' is part of a closed circuit. The field H due to an extended wire carrying current is found by adding up the fields due to the short lengths of current s' in Eq. (10). In the notation of the calculus,

$$H = \int (i'ds'/cr^2) \sin \theta, \tag{10a}$$

the integral sign indicating a vector addition. At the center of a long solenoid, H is uniform and

$$H = 4\pi ni'/cl, \tag{11}$$

where l is the length of the solenoid.

The torque on a coil of n turns carrying a current i in a uniform magnetic field H is found by application of Eq. (9a) to be $L = (niA/c)H \sin \phi$, where ϕ is the angle between the axis of the coil and H, and A is the area of the coil. The ratio of the maximum torque L_{max} to the field H is called the magnetic moment M (see Eq. (2) for electric moment),

$$M = niA/c = L_{max}/H. \tag{12}$$

If the orbits of the electrons in an atom lie predominately in any plane, the atom has a magnetic moment normal to that plane and behaves like a coil. The sum of the magnetic moments of all the atoms divided by the volume is a measure of the state of magnetization and is called the intensity of magnetization I,

$$I = \Sigma M/v. \tag{13}$$

If a bar of iron is placed in a solenoid the effect of the field H is to rotate, perhaps indirectly, the orbits of the electrons in the atoms of the iron so that the orbits become lined up in planes perpendicular to H. The electrons are moving around in the atoms in the same direction as the electrons in the copper wire of the solenoid, counterclockwise as one looks along H, and contribute an additional field which can be shown to be equal to $4\pi I$. As in electrostatics, polarization can be described in terms of the induced charge appearing at the surfaces, the charges balancing out within the material; likewise, magnetization can be described in terms of current whirls i_m flowing around the surface of the iron, the currents within the iron balancing out. Let us assume, for the sake of setting up the picture, that the electron orbits are rectangular and that they touch one another (Fig. 2).

[5] If we arbitrarily set $c = 1$ cm·sec.$^{-1}$, then when $s = s' = 1$ cm, $r = 10$ cm and $f = 1/100$ dyne approximately, i and i' have the magnitude of the electromagnetic unit of current and the dimension of the electrostatic unit. If we set $c = 1$ without dimension, then i and i' are measured in electromagnetic units.

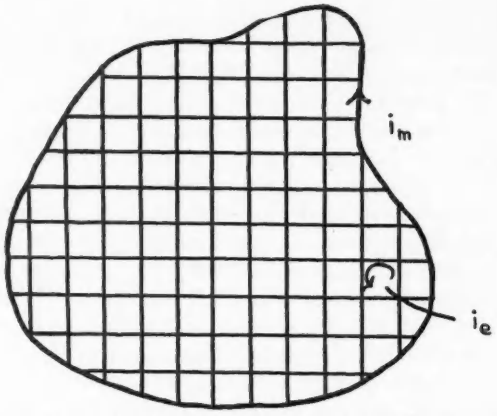

FIG. 2. The orbital currents of the atoms i_e furnish a current i_m around the surface of the iron.

We see that within the material the orbital currents cancel out, the sum of the areas A_e of the orbits being equal to A, the cross section of the iron, and the current i_m around the periphery of one layer of atoms being equal to i_e, the current around each atom. The orbital currents are not, of course, rectangular and the orbits may not touch or may overlap but, in any case, the current at the surface of the iron i_m is of such magnitude that its magnetic moment ni_mA/c is equal to the sum of the magnetic moments of all the atoms $\Sigma i_eA_e/c$. Thus $i_m=(\Sigma i_e/n)(\Sigma A_e/A)$ and the current whirl per unit length of the iron,[6] ni_m/lc, is equal to the intensity of magnetization I, $ni_m/lc=ni_mA/Alc=M/v=I$. The net current around the solenoid and iron is increased from i' to $i'+i_m$, i' remaining constant; hence the field is increased from

$$H=4\pi ni'/cl \qquad (11),\ (11a)$$

to

$$B=4\pi n(i'+i_m)/cl; \qquad (14)$$

thus

$$B=H+4\pi I. \qquad (15)$$

B, the so-called "magnetic induction," is the force per unit length on a current i, in the presence both of the current i' in the solenoid and of the current i_m around the magnetized iron.

If we were to make the definitions of magnetic fields strictly parallel to those of electric fields we should have to define B, not H, in Eq. (9) as equal to the force on a current i, and replace H by B in subsequent equations excepting Eq. (11a) and Eq. (15). However, to the engineer, H is the field due to conduction currents whether in vacuum or near iron and it is well to define it so. Also, H is of more importance than D because it is H, a function of i', rather than B, a function of $i'+i_m$, which is externally controlled, whereas in electrostatics it is usually E, a function of V and $q-q_p$, rather than D, a function of q, which is externally controlled.

The so-called magnetomotive force, defined as $MMF=\int H_s ds$, is formally similar to the potential difference or e.m.f. defined in Eq. (6) but more similar to $V_0=\int D_s ds$. It is useful in describing conditions in a magnetic circuit. $\int B_s ds$ would correspond more to $\int E_s ds$ but is not so useful. There is no necessity for imagining a tunnel cut lengthwise through the iron in order to evaluate the line integral $\int H_s ds$, for H is simply the partial field due to currents i' alone. The average value of the force on an electron due to its motion should be B, the same whether the average is taken along a line along B or across a section perpendicular to B. Taking the line integral just inside the iron and back just outside, $\int B_s ds-\int H_s ds=4\pi i_m/c$. The line integral $\int H_s ds$ within the iron is equal to that just outside the iron and equal to that with the iron removed, the current i' remaining constant.

The ratio

$$(i'+i_m)/i'=B/H=\mu \qquad (16)$$

indicates the fractional increase of the field upon introduction of the medium and is called the permeability.

Inside iron within a solenoid, H is the magnetizing field due to the solenoid alone. In the short cylinder of iron, the intensity of magnetization I and its contribution to the field vary from point to point. Near the ends this contribution is one-sided, hence I has its maximum value at the center. Both the average and maximum values of B and I are less in the short cylinder of iron than in the long one. As a general expression we may write in place of Eq. (15),

$$B=H+aI, \qquad (17)$$

where $a=4\pi$ only in the ideal case of an infinitely long, uniformly magnetized bar. Just as in electrostatics the electrons move over until the elastic return force just balances the (reduced) field E, so the orbits line up until the opposing torques, due to local fields and thermal agitation, just balance the torque due to the (increased) B. For a given value of B at a point, there is a definite value of I and a definite ratio I/B, no matter whether B is obtained with a very strong

[6] The same development applies to spinning electrons.

applied field H and a medium of limited size or with a weaker applied H and a larger medium. This ratio may be found from the ideal case of a uniformly magnetized bar (approximated in the endless toroid ring). By solving Eq. (15) for I and combining with Eq. (16) and Eq. (17), we find

$$I=(\mu-1)B/(4\pi\mu)$$
$$=[(\mu-1)/(4\pi\mu-a)(\mu-1)]H. \quad (18)$$

For a uniformly magnetized sphere, the partial field aI is found, by integrating the surface density of i_m over the surface, to be $8\pi I/3$, whence for a sphere, $a=8\pi/3$, and

$$I=[3(\mu-1)/(\mu+2)](H/4\pi);$$

and for $\mu\gg1$,

$$B=H+4\pi I/3=3H.$$

There is thus no necessity for postulating a "demagnetizing" field.

Just outside the end of the short iron cylinder, B determines the force per unit length on current i (or the force on a moving charge q) due both to solenoid and iron and is equal to the field B just inside the iron but not equal to the average value of B throughout the iron.

In permanent magnets the electron orbits are at least partially lined up in planes perpendicular to the direction of magnetization and i_m is permanent. The field inside the ideal magnet is $4\pi ni_m/cl$, whereas the field outside is found from i_m in the same way that the field outside a slender solenoid is computed; that is, on the axis of a magnet

$$H=(2ni_mA/c)(d/(d^2-l^2/4)^2)$$
$$=2Md/(d^2-l^2/4)^2. \quad (19)$$

The actual permanent magnet is, of course, most strongly magnetized (elementary magnets in best alignment) at its center and l, the length of the equivalent uniformly magnetized magnet, corresponds to the usual "distance between the poles."

To Professor Webster, whose article follows this one, the author wishes to express sincere appreciation for his extraordinary courtesy in reading this manuscript and writing his paper in such a way as to avoid duplication. With Professor Webster's conclusion that it is more logical to define B rather than H as the force on a current, the author agrees. The author has, however, endeavored to strip the classical magnetic field (H') of its fictitious character, allowing the H of this paper to retain as much of the usual meaning as is compatible with Amperian currents. This H has a twofold use: first, it is a very definite part of the total field B, the part most easily computed, that due to conduction currents; second, it is the cause of magnetization in the sense that it is the force (per unit current) which is externally applied. For simplicity, a single sample of iron has been considered. If in any problem it can be ascertained that the fields due to conduction and Amperian currents in other pieces of matter be unaffected by the local magnetization, then these fields may be included in H; otherwise they must be included in the contribution of magnetized matter.

The electric fields E and D and the magnetic fields, B and H, as introduced in this paper, may be shown to lead directly to Maxwell's wave equations (containing only E and H) in a development which further emphasizes the distinctions between these four fields. Lack of space forbids including this derivation.

Facing Reality in the Teaching of Magnetism

DAVID L. WEBSTER, *Department of Physics, Stanford University*

AMONG the various reasons that we, as physics teachers, would give for our interest in physics and our confidence in passing it on to the next generation is the clear, concrete reality of physics. The statements we make to a class in physics are based, not on our personal opinions or tastes, but on nature itself, through experiments with real, concrete things.

In spite of this appeal of reality, however, our lectures often, and quite rightly, deal with unreal mathematical fictions. Rays of light, for example, are not the paths of any real things, or even of quanta, nor do they even include all the points to which the light really goes. Yet they are useful concepts, rightly deserving a place in our lectures on light, until the facts of diffraction and interference demand a better picture. Light waves in an elastic-solid ether may then hold the stage, only to yield it soon to Maxwell's electromagnetic waves, which in their turn must be modified to account for photoelectrons. Reality in light is approached through fictions.

In magnetism, also, it is customary to begin with a mathematical fiction, the magnetic pole, which is sooner or later replaced by Amperian currents, these in turn being specified more definitely as orbital or spinning motions of electrons. If an approach to reality through fictions is best for light, is it, or is it not, best for magnetism also?

In both cases, the approach is in historical order. In magnetism, indeed, it has a better historical basis than in light. For whereas the verdict of reality in light was definitely given to waves away back in 1801, it has only been within the last generation that Ampere's theory of magnetism has become anything more than an attractively simplifying possibility. And whereas Young's experiment is easily verified by a freshman, the most crucial evidence for Ampere's theory still rests on the word of Barnett. Thus, in the teaching of magnetism, the appeal of historical order is clearly for the *status quo*.

But just what is behind the appeal of historical order? Is it not the idea that the individual student is likely to develop like the race? In light that idea is clearly true: the fact that rays of sunlight come into a dusty room in straight lines is familiar to anyone old enough to see straight. But does the idea apply as well to magnetism?

When electric lights were new and motors were mere toys, it certainly did. The compass, the little motor with a three-pole armature, the tangent galvanometer and the college laboratory apparatus for measuring the earth's field, all suggested poles. But today, Lindbergh's compass is an earth-inductor coil; motors have lost their salient poles, replacing them by wires cutting across the field; ammeters of the d'Arsonval type are far more familiar than tangent galvanometers; and even for exact measurements, the international ampere counts ions of silver, which have no obvious relation to the earth's field or to poles. In short, the student's experience and environment now contain very little to be drawn upon for the concept of poles but much for that of a magnetic field as something that pushes a wire in which current is flowing. For him the real nature of a magnet, as simply another current-carrying body to be affected by a magnetic field, need not be approached through any fiction but can be faced directly.

Since teaching is an art, even when the subject taught is a science, we must keep in mind Kipling's "nine-and-sixty ways of constructing tribal lays," even though the subject matter of our tribal lays prevents us from accepting too literally his conclusion that "every single one of them is right." The content of our lectures *must* be right, scientifically, but there are many ways of constructing them. For the field of magnetism one such way is outlined excellently by Professor Warburton in the preceding article and, while the present author prefers another way,[1] such differences are purely secondary. Taking Warburton's way as an example of the simplicity and directness possible under the general idea we both advocate and thanking him most cordially for the opportunity of reading

[1] See Webster, Farwell and Drew, *General Physics for Colleges*, Chap. XVIII.

his manuscript, I shall touch the problem of outlining a course on this basis at only one point; experience shows that this general idea works well in practice.

Among the possible different ways of planning these lectures, one question often arising relates to the distinction between H and B. We agree, as one must in the light of modern evidence, that there is absolutely no difference in kind between these vectors, such as there is between E and D. Thus E, measuring the strength of the electric field, has to do with free space, either outside any matter or between the charged particles of which the matter is made up; but D is a composite of two quantities of quite different kinds, E and the $4\pi P$ that specifies an aspect of the geometric arrangement of these charged particles. H and B, on the other hand, are both simple field strengths. As Warburton has noted, it is not H, but B, that really measures the average value of the field within any piece of iron. B is therefore not a composite quantity like D, but simple. H is likewise simple; but whereas E is real, in the sense that it measures the average strength of the electric field existing within the matter as it is, H measures only the magnetic field that would exist if things were different. As Warburton defines it, H measures the field that would exist if all the iron in the whole apparatus were removed; as many other writers define it, the iron to be removed would be only that taken out by a fine drill running along the lines of force. Both H's are fictitious, in the sense of not representing the field strength really existing within the iron. Warburton's H differs from the real field because in removing all the iron one would remove all its Amperian currents; the other H differs from the real field because in drilling the hole one would leave uncancelled the Amperian currents on its inner surface and these would act like a solenoid, giving a field $-4\pi I$, or $-(B-H)$.

The question is: Since either H is so definitely fictitious, why should we write the formula for the force acting on a copper wire in terms of H, rather than B? The reason for doing this, if we continue to do it, is as stated by Warburton, that H and B are practically identical in copper (at least, with the second of these H's, and with the first also if there is no iron near the wire) and that engineers are accustomed to the use of H. But is this a sufficient reason?

Unipolar induction and the effects related to it appear to me—remembering that both ways are "right"—to furnish a weightier reason on the other side. As Kennard[2] has clearly shown, these effects may be divided into two converse groups, corresponding to practical motor and generator effects. Those of the motor group depend on forces due to currents flowing through magnetized iron. Since it is not H, but B, that determines these forces, those phenomena appear to anyone using H in the force formula for wires to be strange and somewhat confusing exceptions; but with the formula in terms of B, they fit quite naturally into a simple and logically attractive set of principles.

Furthermore, the converse effects, of the generator type, are equally significant in connection with another custom common among engineers, namely that of thinking of lines of magnetic force as able to move and even to rotate in space. Aside from unipolar induction, this idea is logically weak and it always breaks down if examined too closely. Of course, a theory that covers some phenomena and breaks down on others is better than no theory at all; and if it is very much simpler than a more complete theory it may be useful even when the complete theory is known, provided its status is clearly recognized. But in this case, where the incomplete theory is simpler only for a few of the practical problems but unnecessarily confusing for many others, its utility is highly dubious. And when unipolar induction is brought in as a test and it is found that rotating lines of force give false predictions on some very simple phenomena, the case seems clear for the other side.

In both these cases, *B versus H* and stationary lines of force *versus* rotating, we physics teachers are faced with the question: Shall we be bound by engineers' customs? If no questions of fact were involved and one custom was about as logical and concise as another, we might as well save our students the confusion of having to speak two languages. But when the findings of physicists bring out facts such as these, it seems

[2] E. H. Kennard, Phil. Mag. **23**, 937 (1912); Phys. Zeits. **13**, 1155 (1912) and **14**, 250 (1913); Phys. Rev. **1**. 355 (1913) and **7**, 399 (1916).

to me, at least, that the time has come for us to lead the way for the next generation of engineers.

A practical classroom question somewhat related to this of B and H is on the calculation of forces in motors. The wires on the armatures of most present-day motors lie in slots and the field in a slot is not as strong as either H or B (whichever you call it) in the space between the drum and the pole face, nor as strong as B within the drum. Yet either of these two latter vectors, used in connection with the current in the wires, gives the force on the armature as a whole. Why?

In terms of poles, we used to talk either of the teeth between the slots as little salient poles, or of the drum as a whole as having two rather indefinitely-distributed poles. Either way, since the inverse square law is useless with such big and indefinite poles, the easiest way to prove the formula was to go over to the converse calculation of power, through electromotive force, and then to use the law of conservation of energy by saying that if one could calculate the power mechanically, the result would have to be the same.

In terms of Amperian currents, however, the problem is relatively simple. The forces are all of one kind, those of magnetic fields acting on currents, some of the currents being carried by the copper wires and the rest being the uncancelled Amperian currents in the sides of the teeth. Quantitatively, the old way of proving the formula will still work but we have also a more direct way. The field B in a slot is weaker than its average value for slots and teeth together only because of the Amperian currents in the teeth, as in Fig. 1. Therefore the loss of force on each wire, due to this loss of field, is simply the force exerted on that wire by the Amperian currents in the teeth. And by Newton's third law, this force has an equal and opposite reaction, namely the force exerted by that wire on the teeth. The net result, then, is merely a transfer of some of the force from the wires to the teeth, and the torque on the armature as a whole is the same as if the drum were smooth and the wires outside it. Strictly speaking, of course, this analysis could be replaced by one in terms of poles; but practically, since the interaction of the currents in the wires and the teeth is simply that of parallel or opposite currents, side by side, it is simpler in terms of Amperian currents.

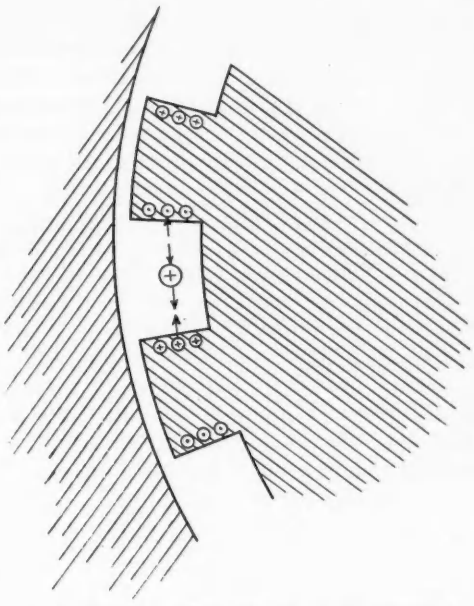

FIG. 1. Transfer of part of the force on an armature wire to the teeth (showing only the part transferred).

Another practical classroom problem relates to the use of iron filings for mapping magnetic fields. Enthusiasm for reality in one direction must not blind us to reality in another; and the value of these maps as an aid in visualizing magnetic phenomena is very real. But they have always been explained in terms of poles, a little pole at each end of each filing. Must we lose them or revert to a false theory to save them? No!

The fact is, we have usually slid on rather thin ice over the question: Why does each filing get magnetized in the direction of its length, so that it will turn, rather than merely get magnetized along the lines of the external field and be content with its position as it is? Perhaps we slide over this question without thinking of it, if bar magnets are so familiar that any bar or filing can readily be assumed to be magnetized along its major axis. But if magnetism is introduced through currents, rather than bar magnets, where do we stand?

One way is to slide over it equally lightly but more frankly by another method: First, demon-

strate purely qualitatively that forces are produced on any movable pieces of iron or current-carrying wires in the presence of any fixed current; then use the iron filings to show that the region where these things happen contains something to be mapped and, purely empirically, that iron filings will draw definite maps; and finally, define the strength of this something by the force it exerts on a current, as outlined by Warburton. This way, in practice, works well.

After that, of course, one must at some convenient time go back to the question of why the filings are so accommodating as to give us this map. Then, if we were following the pole theory, we should talk about self-demagnetizing fields; or by Amperian currents we analyze the magnetization of a bar in the much clearer way set forth by Warburton.

In conclusion, let me note that these examples of the iron filings and the armature-force problem are typical of the way in which the Amperian point of view, even if at first a trifle unfamiliar to anyone thoroughly versed in analysis by poles, works out in the long run to be more straightforward. Let me also repeat for emphasis that the use of B instead of H for calculating forces on copper wires is not a strictly necessary part of the Amperian point of view, even though its possibility seems to me to be one of the advantages of the latter. And finally, let me repeat my testimony from classroom experience—remembering that teaching is an art and therefore rightly different in different hands—that there are some of us, at least, who find the Amperian medium by far the best to work in.

The Physics Museum of the University of Chicago and Its Relation to the New Curriculum

HARVEY B. LEMON, *Ryerson Physical Laboratory, University of Chicago*

(Received August 23, 1933)

THE innovation which was made at the University of Chicago two years ago of utilizing a museum for the purposes of undergraduate instruction in physics had its origin in necessity. Committed to the belief that undergraduate college instruction during the first two years should be designed to give students a broad, yet somewhat deep, general education over the entire field of university activities rather than to initiate them at once into courses designed primarily for the training of specialists, the staff in the physical sciences at once recognized that laboratory work of the conventional sort was entirely out of the question. The proposed general courses were to be required of all students, most of whom would have no previous laboratory experience, and it would be impossible to equip and staff suitable laboratories for their use. Nevertheless, it was equally clear to the majority of those responsible for the new curriculum that any attempt at general education in the physical sciences would be largely foredoomed to failure unless it were possible, by some means, to bring students into direct contact with phenomena. It was argued that one might as well try to interpret literature to students who had never read any books as to try to teach science to those who never had experienced any conscious contact with the phenomena that comprise its source material. In physics, especially, it seemed clear that the conventional laboratory could not be used and that, consequently, the part of the new general course dealing with this subject would leave no lasting impression without the essential laboratory contacts. Since neither horn of the dilemma could be embraced, a compromise had to be effected and this took the form of student museums of physics, chemistry* and geology, now in existence

* At the time of going to press it seems quite possible that the museum of chemistry which has been expensive and very difficult to administer may be replaced by a suitable series of talking motion pictures yet to be developed.

as an integral part of the University's new plan of undergraduate general education.

Since there were no known precedents for guidance in this venture, the cooperation of the newly organized Museum of Science and Industry of this city was sought and readily obtained. This Museum possessed detailed plans for a very extensive museum of physics and these plans in their topical outline showed a surprisingly complete one-to-one correspondence with the syllabus of our proposed general courses.[1]

Plan of the Course

A word about the organization of the Introductory General Course in the Physical Sciences is necessary if the function of the student museum is to be made clear. This course is one of the four which must be passed by all students before they may enter senior college work in any of the divisions of the University. It is a full year course and it covers the fields of astronomy, mathematics, physics, chemistry, geology and some aspects of geography. Instructional methods are graduate rather than undergraduate in type; that is, attendance at the three weekly lectures, at the one or two small-group discussion sections to which each student is assigned, at the Museum and at the many short quizzes and informal written examinations is not required of any one. Satisfactory knowledge of the material covered is judged and recorded solely by the student's performance on a six-hour comprehensive examination, partly objective and partly subjective in type, which is given at the end of the year. Despite this freedom from requirements, we are finding that, except for a very small minority of superior students capable of intensive work by themselves, attendance at lectures, classes, quizzes, museums, etc., is as large as it was when such attendance was required.

The materials placed at the disposal of the students and the instructional devices employed during the course are as follows:

The syllabus

For reference on his desk during the year the student has a detailed syllabus of the subject matter of the entire course. The syllabus is comprehensive and contains detailed references to textbook material, problem assignments, descriptions of museum experiments, some of them illustrated, and the more important tables and diagrams. It is still maintained in a form that can be changed from year to year and it has been altered each year as experience has dictated. Blank pages inserted between each page of type make the syllabus useful for note taking in lectures and classes.

Textbooks and references

Some six or eight textbooks, dealing with the various sciences covered, make up a rental set which is presumably also on the student's study desk during the entire year. Those for physics are of the type best described as intermediate between descriptive high-school and analytic college texts. In addition, in a special college library multiple copies of many other books are available, some of a popular nature, others more advanced and some historical. Partial or complete reading of certain of these books is suggested.

Demonstration-lectures

Lectures are given regularly three times a week in a specially equipped room accommodating about 250 students in each of two or three sections. It has been found that the most successful lectures are those that are given informally and in conversational style, continually interspersed with questions which the instructor answers if voluntary responses from the class at the moment are inadequate. The lecturers are carefully selected for maturity and experience in their respective fields and also for their ability as expositors of the subjects. Insofar as possible it is attempted to enlist the aid of men of distinction—men known for their creative work in research or in teaching, or preferably both.

The museum

Further contacts with phenomena, in addition to those made available on the lecture table, are afforded by the teaching museums of astronomy, physics, chemistry and geology. Astronomy is served at present by the resources of the Adler Planetarium of this city, generously put at the disposal of the regular course instructors for lectures and demonstrations through the courtesy of its board of directors and its executive head, Dr. Phillip Fox. The other museums are either on or near the campus.

Talking motion pictures

Phenomena that are not suitable for treatment by any of the foregoing methods are presented in a program of

[1] We wish to acknowledge gratefully the splendid cooperation which we received from Mr. Rufus Abbot, president of the board of trustees of the Museum, from the board, from Mr. O. T. Kreusser, the director, and from Dr. A. M. MacMahon, curator of physics. Dr. MacMahon was largely responsible for the plans for the lay-out of space, and to him and his colleagues we also owe the loan of about one-half of the present equipment and assistance in its installation and maintenance. The remaining experiments and exhibits were assembled from the existing resources of Eckhart and Ryerson laboratories of the University.

talking motion pictures still in the process of development under the combined efforts of the staff of the University and of the Erpi Picture Consultants, a subsidiary of the American Telephone and Telegraph Company. Films covering the subjects of energy and its transformations, the molecular theory of matter, electrostatics, oxidation and reduction, sound, magnetism and electromagnetism are now completed or in process. About twenty such films is the preliminary goal in the physical sciences alone.

Discussion groups

The 650-odd students in the course are divided into groups of 20 to 25 students each for discussion and recitation purposes. These groups meet once a week and have insofar as possible the same instructor throughout the year. These instructors likewise are selected as carefully as possible with reference to their teaching ability and their understanding of and interest in student problems.

Examinations

Working in the closest cooperation with the course directors, lecturers and discussion instructors is a group of examiners, representatives of whom attend lectures and all staff meetings. This completes the organization.

The Physics Museum

From the foregoing it should be clear that the physics museum is only a small part of a comprehensive and elaborate organization for education. Its unique character among all museums springs from this fact. Although it has many visitors from among special groups of the general public and is under continually increasing demands from the outside, its entire *raison d'être* is to be found in the needs of our particular problem of instruction and its major value lies in what it can contribute to the special needs of the curriculum of general education in the College.

The museum is housed in temporary and entirely inadequate quarters, the chief disadvantage of which is a rather remote location from the other activities of the students in these courses. As was previously stated, the equipment is partly borrowed from another organization and partly assembled from apparatus which in turn has been borrowed from other student and research laboratories. It has been operated for nearly two years without a budget of its own, indeed at almost negligible cost. A scholarship to defray the expense of a single student attendant throughout the year has been the largest single item of the expense of maintenance and this exceeds the sum total of all other expenses, except that of the original installation. The department of physics has, of course, been generous in allowing the occasional use of its shop facilities and of some of its mechanical staff.

The museum building has about 3000 sq. ft. of floor space; this is divided into three rooms and part of a wide corridor on to which the rooms open on either side. Being interior rooms in a one-story structure, the rooms are sky lit and windowless and hence ideal for exhibition purposes. The wall area for charts, etc., and the lineal footage available for experiments has been greatly increased by the installation of temporary partitions which create circuitous paths and impose a definite direction of circulation upon the visitor.

The three rooms house a total of about 125 experiments and exhibits, the majority of which are either self-operating or student-operated by means of push buttons or similar easily manipulated devices. In each sequence of subjects in any field the attempt is made to lead the visitor from the most simple and elementary aspects through a sequence of increasing complexity to one or two experiments of the utmost refinement and precision.

In *mechanics*, for example, the sequence begins with some metal rings that jump about and remain suspended without visible support. This is introduced solely for the purpose of making it clear to the student at the outset that he already has an intuitive knowledge of a very fundamental law of mechanics. He is led to see that his attempt to discover the trick of this device is evidence that he possesses some knowledge of the principle of inertia. The mechanics sequence concludes with the Cavendish experiment (Fig. 1) from which the mass of the earth can be found, at least to its order of magnitude. Any student willing to take considerable pains could obtain an idea as to the value of the first few significant figures in the gravitational constant.

Other subjects covered in mechanics are: the remaining laws of motion, including applications to rotational motion through the principle of conservation of momentum; the motions of the earth, sun and moon on a small planetarium; exhibits of the transformation of energy; mechanical advantage; fundamentals of hydrostatics and hydrodynamics (Fig. 2). A corner is

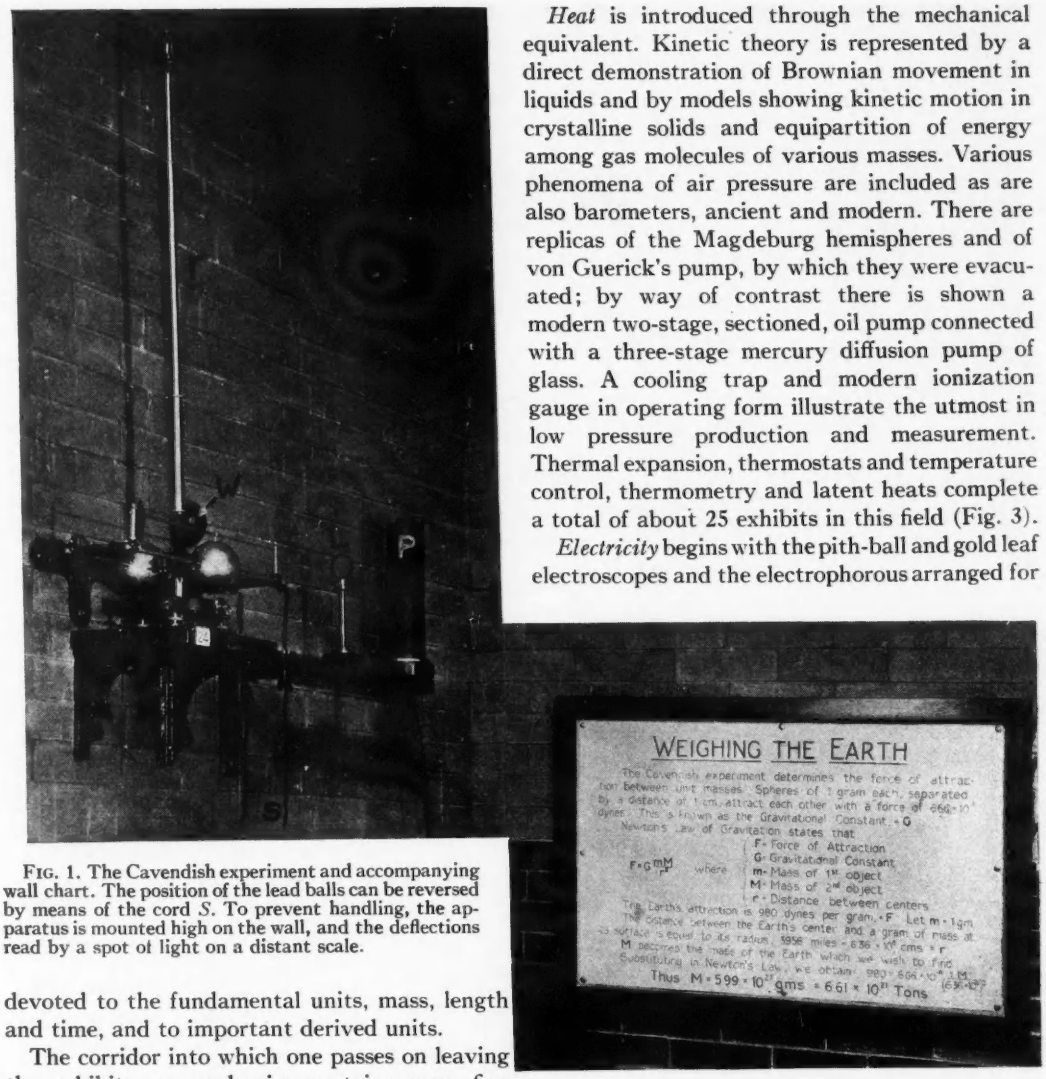
WEIGHING THE EARTH
The Cavendish experiment determines the force of attraction between unit masses. Spheres of 1 gram each, separated by a distance of 1 cm, attract each other with a force of 666 × 10⁻⁷ dynes. This is known as the Gravitational Constant = G
Newton's Law of Gravitation states that
F = G mM / r² where
F = Force of Attraction
G = Gravitational Constant
m = Mass of 1st object
M = Mass of 2nd object
r = Distance between centers
The Earths attraction is 980 dynes per gram. = F. Let m = 1gm
The distance between the Earths center and a gram of mass at its surface is equal to its radius, 1956 miles = 6.36 × 10⁸ cms = r
M becomes the mass of the Earth which we wish to find.
Substituting in Newton's Law, we obtain 980 = 666 × 10⁻⁷ × M / (6.36×10⁸)²
Thus M = 5.99 × 10²⁷ gms = 6.61 × 10²¹ Tons

FIG. 1. The Cavendish experiment and accompanying wall chart. The position of the lead balls can be reversed by means of the cord *S*. To prevent handling, the apparatus is mounted high on the wall, and the deflections read by a spot of light on a distant scale.

devoted to the fundamental units, mass, length and time, and to important derived units.

The corridor into which one passes on leaving the exhibits on mechanics contains some fine exhibits of sectioned and movable steam engines, turbines and a twelve-cylinder Liberty gasoline engine; also some exhibits in operating form of various gears and linkages for the transmission of power. This material is not part of the permanent collection nor is this subject-matter included in the course. Applications must be subordinated to general principles because of the limitations of time, although their relations to the principles are, of course, made obvious throughout the course.

Heat is introduced through the mechanical equivalent. Kinetic theory is represented by a direct demonstration of Brownian movement in liquids and by models showing kinetic motion in crystalline solids and equipartition of energy among gas molecules of various masses. Various phenomena of air pressure are included as are also barometers, ancient and modern. There are replicas of the Magdeburg hemispheres and of von Guerick's pump, by which they were evacuated; by way of contrast there is shown a modern two-stage, sectioned, oil pump connected with a three-stage mercury diffusion pump of glass. A cooling trap and modern ionization gauge in operating form illustrate the utmost in low pressure production and measurement. Thermal expansion, thermostats and temperature control, thermometry and latent heats complete a total of about 25 exhibits in this field (Fig. 3).

Electricity begins with the pith-ball and gold leaf electroscopes and the electrophorous arranged for student operation; includes an exhibit of a static machine combined with a demonstration of lightning rod protection of buildings; continues with magnetism, electromagnetism and measurement of current—including exhibits of various household devices with meters so calibrated as to indicate relative costs of operation—and of transformers, simple dynamos and motors. It concludes with several demonstrations of eddy currents and one of a simple polyphase generator and induction motor.

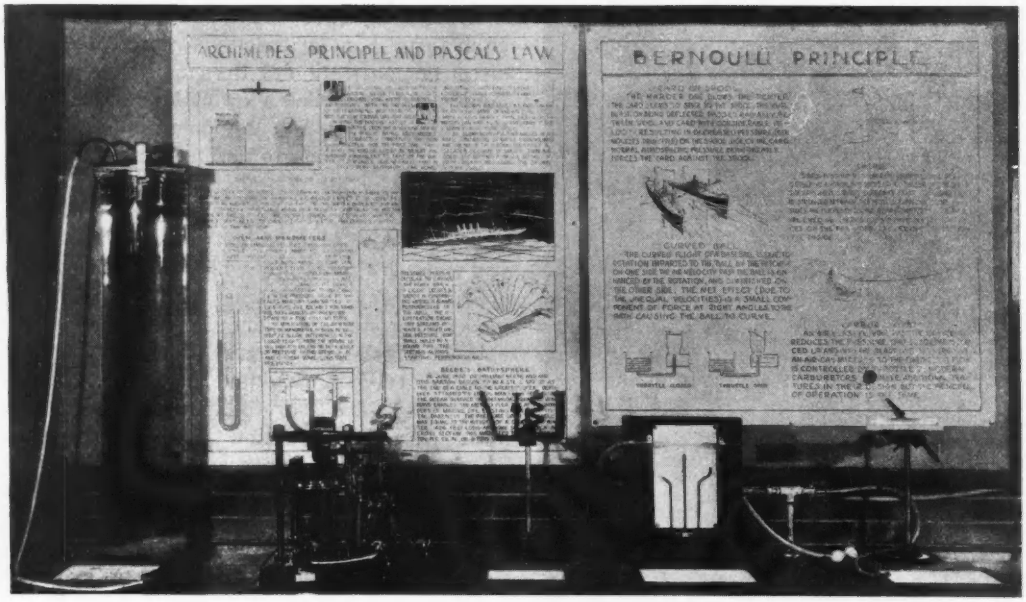

FIG. 2. Mechanics of fluids. The exhibits are, from left to right: Cartesian diver; hydraulic press; Pascal's paradox; a Bernoulli manometer; a ball on a jet.

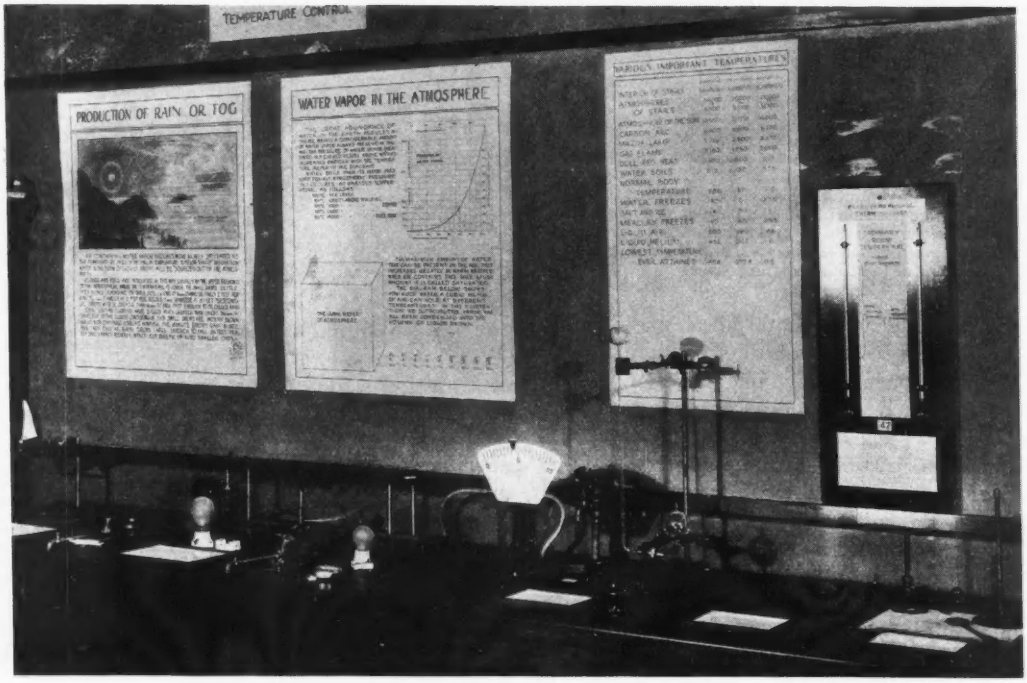

FIG. 3. Temperature measurement and control. From left to right: pulse glass, thermostats, expansion of wire, vapor pressure and other thermometers, ball and ring showing expansion.

Scattered along through the section on electricity and magnetism are a number of very fine historical exhibits, replicas of such things as Sturgeon's first magnet, the first motor by Jacobi, Henry's large electromagnet and his first quantity magnet, the first telegraph, early galvanometers by Henry, etc. Because of the general and broad objectives of these courses it was anticipated that there would be a considerable interest in such exhibits. It is to be recorded, however, that there has been almost no interest in them; moreover it has not been possible with such efforts as we have had time to make to stimulate such interest. The reason is not far to seek. The physical sciences open up an entirely new realm of information and require new types of study and close concentration in reading. They demand close and well-ordered reasoning which is new to most of the students entering this field for the first time. So much time and attention are needed for getting an understanding of the fundamental subject matter that there is none left, at the moment, for the more broadly cultural matters such as the history of science.

Very broadly organized courses, dealing solely with matters of historical development and designed for upper-classmen and graduate students, have been worked out for initial offering during the present year by a group representing all departments of science. In connection with this program on the history of science we shall probably find the historical aspects of our museums of the greatest value.

The presentation of *wave motion*, *sound* and *light* is introduced by continuously-operating mechanical models showing transverse and longitudinal, and progressive and stationary waves. A rather limited series of demonstrations in sound includes the bell in vacuum, limits of audition, beats resonance and sound filters. This is amplified by charts of classical achievements in the spark photography of sound wave fronts, both from audible sparks and from disturbances caused by projectiles. We have as a gift from the late Thomas A. Edison to our collaborators, The Museum of Science and Industry, a replica of his first phonograph and pages of his notes thereon. The museum material on sound has been effectively supported by two reels of talking motion pictures. This medium of communication is peculiarly adapted to tell the story of the physical character, the physiological and mechanical mechanisms of sources and receivers, and the applications in this field of physics out of which it has developed.

In the subject of *light* the museum reflects and emphasizes in many ways the work of the distinguished leader who during the long years of his association with the University did so much for the advancement of knowledge in this field. In addition to the simple and more common demonstrations of reflection, refraction, properties of simple lenses and mirrors and the important types of optical instruments, early devices developed by Michelson are displayed and there is a working full-scale apparatus that enables the visitor to demonstrate clearly to himself the fact of the finite speed of light (Fig. 4). The essential part of this last apparatus

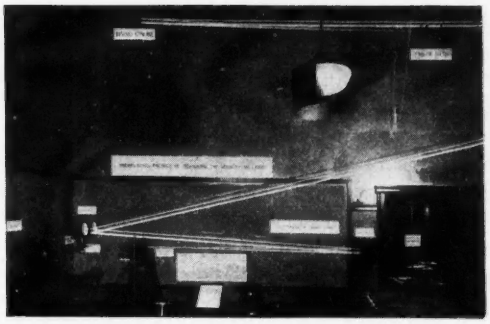

FIG. 4. Michelson's apparatus for measuring the speed of light.

is a comparatively recent steel octagon used by Michelson in his work in California. The mirror arrangements and lay-out are obviously adaptations of the more recent forms of his famous experiment. While at present only qualitative in character, showing a very considerable displacement of the beam when the mirror is spinning, it is hoped that another year will see the installation of simple stroboscopic apparatus that will record the speed of the mirror simultaneously with a setting of the ocular cross hair on the displaced image. As soon as this is done the observer will be able to *measure* the speed of light over the 65-ft. path to a precision of at least one percent.

Charts are used to describe in detail the various

parts of the electromagnetic spectrum: a short wave sending and receiving set illustrates the longer waves; infrared is shown by means of a radiometer mounted and operating on that portion of the chart; the visible range is projected on the chart and its small extent emphasized. Near ultraviolet and the slender amount of our knowledge with respect to its physiological properties is emphasized in connection with an exhibit of the various types of so-called "sunshine" or "health" lamps. Various spectra of the latter are pointed out as the sole criteria of the physical characteristics of their radiation.

X-rays follow in the sequence and they are placed so as to emphasize their origin and relation to the discharge of electricity through gases. A striking exhibit of discharges at various stages of evacuation runs continuously nearby and the x-ray stage in this is pointed out. The origin of x-rays in electron impacts serves as a point of departure for a more general study of properties of streams of electrons and the different ways of obtaining them. Thermionic and photoelectric effects come here and the final sequence, still incomplete, will attempt to make clear the dual character of crystal analysis in the study of x-ray spectra and in the reciprocal analysis by the x-rays of the crystal grating. The development of modern ideas as to the nature of atoms and molecules could follow directly from the analysis of crystalline matter but it has seemed to us unwise to give to the students at this stage any very extensive presentation of modern physical theories of atomic structure. A brief exposition of the Bohr theory and a vigorous emphasis that both radiation and matter possess corpuscular and undulatory properties are given in the lectures. To give further details tends to lead to beliefs in the reality of special models, and, as we have found by experience, to convictions that the physicist knows much more about these things than he really does. Only through a complete technical study of the matter over a period of several years does a student learn to differentiate between fact and fancy in this field. It deserves no large place, we believe, in an introductory course.

The manner in which exhibits are mounted for display is very simple. Unlike many other types of museum display, there is no need for stage-like settings or lighting, or for large exhibits, since the number of visitors at any time before any given exhibit is never more than two or three. Narrow tables are built in around the walls and along each side of the six-foot partitions that divide the rooms. These are covered with a heavy grey-green floor linoleum and make, with the brown-stained woodwork, a quiet and inconspicuous appearance.

The necessary electric, gas, compressed air and water outlets and small sinks sunk in the table tops were of course planned after the lay-out of experiments was complete. Wall charts cover nearly all of the space behind the tables; the planning and execution of them required fully as much time and effort as did the exhibits themselves. Typewritten placards framed under glass go with each exhibit. These provide a concise explanation of the phenomena shown, their relation to the other exhibits by cross reference, and any necessary directions for operation or instructions as to what should be observed. Cautions which must be observed are printed in red and students are drilled to read and study them before attempting to manipulate the exhibit. Since the student visitors to this museum are also in frequent attendance at lectures it is a relatively simple matter to inculcate in their minds the proper attitude with respect to the museum's use. In fact, there has never been a case of damage or theft on the part of any member of the student body. The same cannot be said for the behavior of other groups that have requested admission. Indeed, while maintaining a policy of admitting as many visitors as possible from other schools, especially senior high schools, and from clubs and other adult groups, it is found necessary to provide for them one guide for every 15 persons, approximately. To visitors of this type the museum is a place of interesting entertainment; they fail for the most part to read the charts or directions and get little understanding or value out of the visit unless accompanied by a guide who explains and interprets as they proceed.

The results as to attendance may be briefly summarized. During the first year of operation the museum was put together only slightly in advance of the student use of each individual section. In spite of lack of completeness, the

attendance during the first year was: students 645, visitors 377, total 1022. During the second year enrollment in the physical science course approximately doubled, whereas student attendance at the museum nearly trebled, being 1554. Visitor attendance was 697. In addition, an evening series of lectures for adults, which was followed by a visit to the museum, added 761 more visitors. The total for the second year was 3012, nearly three times that of the first year.

Because of increased familiarity of both staff and students with the needs of the new curriculum and increasing experience in handling it, the museum has played a very much greater part in the students' experiences during the second year than it did during the first. This is obvious to any careful observer who watches the way in which many students are using the museum more and more after the manner in which they would use a reference library. Many of them obviously come prepared to devote themselves to a certain experiment or to some small group of related ones, with respect to which they have already informed themselves somewhat. They come armed with the syllabus, and often with reference texts, which are consulted together with the printed directions and explanations of the experiments, before any manipulations are made. Of course there is still a considerable amount of undesigned roaming about but much of it frequently terminates in a focus of interest and real study.

The continuous presence of an attendant, preferably one in each room, is absolutely necessary. "Without this there cannot be avoided that lamentable bane of even the greatest museums—*inoperative experiments*." This is regarded in our museum as the one intolerable event, the one unforgivable fault on the part of an assistant. His first duty is to see that everything works before the doors open. But he is also there to help students clear up points regarding experiments and the general principles which they involve. His rôle is precisely that of a good laboratory instructor, who has eyes everywhere, who drops a word here or there if there is difficulty, who asks a leading question or so to stimulate thought and interest if it flags but who never indulges in full and detailed lectures and explanations.

To sum up, after two years' experimental trial the museum of physics has assumed a sufficiently effective and necessary place in connection with the general courses so that recognition of the importance of its place in the University has resulted. A policy, not only of maintaining it, but of improving the present obvious defects in housing and location and of ultimately providing a budget for maintenance, has been assured as soon as circumstances permit. It is also intended to make it independent of the Museum of Science and Industry, its foster parent, cordial and kindly as this association has been. Furthermore, although the sister physical sciences of astronomy, chemistry and geology, possibly even mathematics, face quite different problems in museum development and maintenance, some of them much more difficult, there has arisen out of the present venture a real desire on the part of several men in these fields to attempt similar enterprises for the purpose of instruction.

Student Disabilities in the Mathematics of First-Year College Physics

WILLIAM R. LUECK, *Department of Education, University of Iowa*

IT is a well-known fact that the course in first-year college physics contributes materially to the high percentage of failure among college freshmen. The number of failures is undoubtedly augmented by the inability of students to solve the mathematical problems required in the course. The writer does not believe that mathematical weakness is the chief factor in physics failures. It is, however, a contributory item which merits attention.

Difficulty in problem solving may be due (1) to a lack of knowledge of physics principles and (2) to disabilities in the necessary mathematical skills. It is with the latter of these two categories that this study[1] is concerned. It treats primarily of student disabilities in the arithmetical and algebraic skills which investigation has shown are required for solving the mathematical problems in first-year college physics courses. Specifically it aims to determine the designated operations in these two branches of mathematics that are difficult for students, and their degree of difficulty.

METHOD OF PROCEDURE

A test was constructed that embodied all the arithmetical and algebraic skills required in physics-problem solving insofar as these were known at the time this study was in progress. In constructing the test, the writer used the data of Scribner's[2] analysis as a basis and subsequently checked the included skills against the studies of Baskerville[3] and Sharar.[4] An attempt was made to keep the number of skills in any one item at a minimum with the result that only one skill is included in most of the items. A few of the exercises in the test[5] include several skills, but the number in any case does not exceed three.

This test was sent to five Iowa colleges for administration in first-year physics courses. Preliminary to testing, the examiners were requested to read the following directions:

> This is a test on the mathematics which you have to use when solving problems in physics. Work steadily until you are through. Remember that the dot (.) is used in decimal quantities only and does not indicate multiplication. When you are asked to simplify an expression, be sure to reduce the answer to lowest terms. You will be given time enough to finish. You may begin now.

The test was given near the end of the college year. Two colleges used it as a final examination. A total of 230 completed tests were returned to the investigator.

In order to determine the reliability of the test, the scores for each student on the odd and even numbered items were determined. By finding the product-moment coefficient of correlation between these two series of scores and by the subsequent application of Spearman's formula as given by Garrett,[6] the reliability of the test was found to be 0.966 ± 0.004. No attempt was made to arrange the items of the test in the order of increasing difficulty. This step was not taken for two reasons: (1) The study was intended to approximate classroom conditions. In his daily work the student performs the skills as required by the assignment and not in a fixed order of difficulty. (2) The projected test was sufficiently long (145 items) so as to insure high reliability. Any increase in reliability due to the arrangement of the items in the order of ascending difficulty must therefore be very small.

To obtain the various disabilities of the students in question, all items incorrectly solved by them were analyzed. An attempt was made to ascertain the ultimate difficulties involved in the

[1] The study reported in this article is only a small portion of a more extensive investigation. Reference 5 gives a brief survey of the complete study.

[2] Helen Q. Scribner, *Analysis of the Problems in Stewart's "Physics,"* University of Iowa, Master's Thesis, 1929.

[3] Charles W. Baskerville, *Analysis of the Problems in "Physics for Colleges" by Sheldon, Kent, Payton and Miller,* University of Iowa, Master's Thesis, 1931.

[4] Paul B. Sharar, *Analysis of the Problems in Duff's "Physics for Colleges" for the Specific Algebraic, Geometric, Higher Arithmetic, and Trigonometric Skills Found in Their Solutions,* University of Iowa, Master's Thesis, 1931.

[5] For a list of the items used in the test see W. R. Lueck, *The Arithmetical and Algebraic Disabilities of Students Pursuing First-Year College Physics,* University of Iowa Studies in Education **8**, 45–48, Oct., 1932.

[6] H. E. Garrett, *Statistics in Psychology and Education,* p. 271, Longmans, Green and Company, New York, 1930.

items. If it was clearly evident that a student had obtained a wrong answer merely because of an error in computation his difficulty was recorded as such.[7] Errors not computational in nature may be termed *difficulties in method*. These were recorded in two ways: (1) whenever possible the specific error was isolated and stated; (2) when the exact difficulty did not become apparent to the investigator after careful analysis, the operation or process in which it occurred was stated. While *computational errors* are important, they are of less consequence to the teacher of college physics than difficulties in method. Hence, this article will be concerned with the latter only.

Results

A total of 120 describable classes of difficulties was found. Sixty of these, or all those occurring with more than 13 percent of their possible frequency, are included in Table I. The number of errors found during the analysis was 7527. The mean number of items solved correctly was 112. There were 145 items in the test. Hence 77 percent of the items were solved correctly.

The percentage of error was highest in the manipulation of expressions involving fractional, positive and negative exponents. Operations involving positive and negative but not fractional exponents were next in point of difficulty. Negative exponents were greater obstacles than the positive variety. Radicals were more familiar to these students as indicators of required roots than were fractional exponents. When exponents were used with the number ten as a base, their difficulty was slightly decreased.

The solution of equations by the method of multiplying one equation by the other presented considerable difficulty, 31 percent of the pupils failing on this item. Solution by division, addition or subtraction gave less trouble.

In general, decimal operations with arithmetical numbers gave little trouble to the students but exceptions occur. Items involving addition and subtraction of decimals in horizontal series and expanding a quantity like $(0.02)^3$, were solved incorrectly to the extent of 25 percent. When decimals were used in algebraic operations, the percentage of error was increased. The greatest inaccuracy in decimal operations (31.5 percent) occurred in changing quantities like 0.003 and 2.3 to percentages.

[7] *Computational errors* are those which occur in adding, subtracting, multiplying, dividing, carrying and borrowing.

Summary

In general the results of this study indicate that the following topics are difficult for students of first-year college physics: (1) negative, fractional and positive exponents with either literal or numerical bases; (2) simultaneous equations solved by multiplication and division; (3) linear equations involving exponents, fractions and decimals; (4) factoring in algebra; (5) algebraic fractions, especially finding the least common denominator and clearing equations of fractions; (6) decimals in connection with algebraic quantities; (7) the more complex items in multiplication and division of arithmetical fractions; (8) relationship between percentage and decimals.

Educational Implications

Some cautions are necessary before interpreting the results obtained. It should be remembered that the number of algebraic and arithmetical skills required to be performed by the students in this study is a maximum; that the student who is not required to solve many problems, likewise will not use all the skills herein contemplated; and that some of the operations in which pronounced disabilities were found are of infrequent occurrence in physics-problem solving. On the other hand, such errors as were detected by the test are of such a persistent nature that the usual drill on mathematical operations throughout the year has failed to eliminate them.

Different ways of indicating the same operation are not of equal difficulty. To the mathematician, solving the equations $a^{\frac{1}{2}}=3$ and $\sqrt{a}=7$ requires the same operation. Nevertheless, the percentages of error on these items were 68 and 30, respectively. Hence, it is necessary that students be taught the several ways of indicating the division of fractions, the extraction of roots and other similar operations.

Some of the students of beginning physics have had considerable mathematics in college. Others

TABLE I. *Percentage of incorrect responses by students of first-year college physics to sixty mathematical operations required in physics problem solving.*

Number	Disability or operation	Percentage of error
1	Solve $a^{\frac{1}{2}}=3$	68
2	Simplify $\frac{r^{-5}}{r}$	67
3	Simplify $[(10)^{-6}]^{\frac{1}{2}}$	64
4	Simplify $[(10)^{+6}]^{\frac{1}{2}}$	62
5	Simplify $\frac{r^2}{r^{-3}}$	60
6	Change 0.00001 to a power of 10	57
7	Simplify $\frac{(10)^4}{0.4}$	54
8	Expand $(10)^{-6}$	53
9	Simplify $\frac{16a^2-4ab}{4a-b}$	53
10	Expand $\frac{1}{(10)^{-6}}$	50
11	Expand $\frac{1}{(10)^6}$	48
12	Simplify $\frac{(10)^6}{\frac{2}{3}}$	43
13	Solve $\frac{2}{3}a=-111$	41
14	Simplify $\frac{r^{-4}}{r^{-2}}$	40
15	Simplify $\frac{18c+4b}{-2}$	39
16	Clear $\frac{a}{c-d}=\frac{c}{d}$ of fractions	38
17	Solve $-\frac{1}{2}a=30$	36
18	Change 10,000 to a power of 10	35
19	Perform the operation $\sqrt{(10)^6}$	33
20	Solve $0.4a=-16$	33
21	Change decimals like 0.003 and 2.13 to percents	32
22	Solve two simultaneous equations by multiplication	31
23	Simplify $\frac{r^2}{r^3}$ and $\frac{r^4}{r^6}$	31
24	$\frac{180h-16}{4}=$	31
25	Find the least common denominator of $\frac{3}{re}$ and $\frac{2}{r^2}$	31
26	Expand $(10)^{-8}$	30
27	Simplify $\frac{4a^2-4ab}{a}$	30
28	Solve $2ab=16b$ for a	30
29	Solve $\sqrt{a}=7$	30
30	Divide a proper fraction by a whole number, $\frac{\frac{3}{7}}{3}$	28
31	Expand $(2)^4$	27
32	Solve $\frac{a}{105}=-5$	26
33	Use decimals in series, $(2.0-0.10+1.3)$	25
34	Divide a whole number by a fraction, $\frac{36}{\frac{1}{3}}$	25
35	Expand a decimal quantity, $(0.02)^3$	25
36	Simplify $\frac{4r^2(10)^6}{r}$	24
37	Expand $(10)^6$	23
38	Used the wrong process, as addition for multiplication	23
39	Clear $\frac{3}{n}=\frac{4}{a}$ of fractions	23
40	Solve $\frac{a}{(10)^2}=2$	21
41	Solve $\frac{a}{-3.4}=-2$	20
42	Using the decimal coefficient in simplifying $0.8a(4a+6)$	20
43	Divide a proper fraction by a whole number, $\frac{\frac{3}{5}}{6}$	20
44	Solve $a+\frac{3}{2}=4$	20
45	Solve $\frac{a}{d}=20$ for a	20
46	Failed to obtain the least common denominator	20
47	Divide an equation by another equation	19
48	Divide arithmetical fractions, $\frac{2}{7}\div\frac{3}{5}$	18
49	Simplify complex algebraic fractions, $\frac{\frac{a}{c}}{\frac{b}{c}}$	17
50	Multiply arithmetical fractions, $\frac{1}{8}\times\frac{3}{5}$	17
51	Solve $\frac{a}{0.25}=-4$	17
52	Solve $\frac{a}{-3}=11$	17
53	Expand $(3)^3$	17
54	Change a mixed number to an improper fraction, $(10\frac{1}{4}$ to $\frac{41}{4})$	17
55	Difficulty with $(6\times(10)^2\times\frac{2}{3})$	16
56	Difficulty with negative exponents in multiplication	16
57	Multiply a decimal by an algebraic fraction, $0.11\left(\frac{2}{c}\right)$	15
58	Divide algebraic fractions, $\frac{a}{3}\div\frac{v}{t}$	14
59	Faulty cancelling in $\frac{10a}{5b}$	14
60	Change $\frac{7}{4}$ to a decimal	13

have had but the minimum required in high school. The evidence presented by this study indicates a tremendous range of talent in mathematical equipment. It is a task of instructors in physics to see that every student in their classes has command of the essential skills in the mathematics of first-year physics according to the emphasis given to this aspect of the work.

Although three of the five schools gave some attention to teaching mathematics in their physics classes, the results seem to indicate that such incidental teaching is of little value. The

disabilities in fractions, decimals and exponents which were evident in the early tests were also found on the final tests in spite of the fact that some of the less capable students were dropped from classes at the middle of the year and did not take the final tests.

Textbook writers can assist in avoiding confusion. Many errors were made because a certain formula contained the letters d and d', the students substituting for the wrong letter. There seems to be no valid reason why two distinct letters could not be used.

We can expect some help from maintenance procedures in high school but these are not sufficient because of the specific nature of the mathematics in physics and the lack of an adequate background in the science on the part of the students. The chief task rests upon the teacher of college physics. His procedure in a systematic attack on disabilities in problem solving will consist of several distinct steps.

(1) It is necessary that a test, such as the one described on previous pages of this report, or suitable portions of it, be given at the beginning of the year. This will reveal the difficulties of the students and the magnitude of the task confronting the teacher.

(2) The second step includes the construction and utilization of suitable drill materials. Each student should practice only on items offering considerable difficulty to him. Some recitation time will also have to be given to the work.

(3) After a period of concentration on the mathematical skills offering difficulty, a second test should be given to determine if the various skills have been mastered. This should be followed by further teaching if necessary.

(4) Finally, there should be some intensive teaching on the application of the skills in actual problem solving. Every student should have a set of model solutions accompanied by full explanation of the operations and of the physics principles giving rise to them.

EDUCATION is the acquisition of the art of the utilization of knowledge. This is an art very difficult to impart. Whenever a textbook of real educational worth is written, you may be quite certain that some reviewer will say that it will be difficult to teach from it. Of course it will be difficult to teach from it. If it were easy, the book ought to be burned; for it cannot be educational. In education, as elsewhere, the broad primrose path leads to a nasty place. This evil is represented by a book or a set of lectures which will practically enable the student to learn by heart all the questions likely to be asked at the next external examination.—A. N. WHITEHEAD.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

Some Lecture and Laboratory Experiments in Aeronautics

E. G. RICHARDSON, *Armstrong College, Newcastle-upon-Tyne, England*

DURING Christmastide, 1932, the writer had occasion to deliver two public lectures of a popular nature at Armstrong College under the title of *Flight—Yesterday, Today, and Tomorrow*. In spite of this somewhat grandiose title, it cannot be claimed that there was any feature in the lectures themselves which distinguished them from other lectures given in similar circumstances; but as it was a tradition that these Christmas lectures should be largely experimental in character, a number of experimental demonstrations were made and possibly an account of these, most of which, it is believed, are new, may be of service to those who are asked to give similar lectures. As, further, some of the experiments can readily be adapted to give quantitative results in the laboratory, they may be of service to those whose lot it is to train young aircraft engineers.

The object of the lectures was to illustrate the progress of the conquest of the air by man, beginning with the balloon and ending with the rocket plane, which, it was suggested, would form the aircraft of the future.

It was first necessary to show how the balloon gets its "lift" from the difference in the density of the gas inside the envelope and that of the atmosphere outside and a number of experiments were performed to illustrate this point.

(1) Two rubber toy balloons were expanded to the same size by filling them with coal gas and hydrogen, respectively. Small weights were hung on each until they just failed to rise, thus showing the difference in lifting power. They were then released simultaneously and their rates of rise to the ceiling compared. It is essential for the success of this experiment that the gases should be at the same pressure; this may be tested by a simple U-tube manometer. The lift-ratio is approximately 1 : 8 on a weightless balloon. When inflated to the same pressure the balloons should be of the same size and this involves a little care in the choice of two suitable balloons. If these precautions are taken, the rates of rise in a fairly high lecture theatre are convincingly different.

(2) A rigid hollow sphere containing hydrogen was balanced by a counterpoise weight on the opposite side of a pivot. This apparatus was placed under the bell jar of an air pump and the air was pumped out to illustrate the loss of lift of a balloon or dirigible when approaching its "ceiling."

(3) With an expansible envelope, however, some of the lift is retained by the increased displacement of the balloon in the rarer regions of the atmosphere. This may be shown by putting a partially deflated balloon under the bell jar and pumping out the air. This is indeed the very old experiment of Robert Boyle,[1] who did it with a dried, shrivelled apple. This partial deflation of a balloon at the surface of the earth when it is intended to rise to great heights is very apparent in the photographs of Professor Piccard's recent balloon flight from Brussels into the stratosphere, slides of which were shown.

A number of experiments were then shown to illustrate the relation between the resistance experienced by the aircraft and the flow of air round it. To illustrate the classical theory of fluid flow, a Hele-Shaw apparatus of the conventional type was constructed[2] to show the

[1] *Nova experimenta de vi aeris elastica*, 1662.

[2] Trans. Inst. Naval Architects **40**, 21 (1898).

stream lines in the flow of the thin layer of fluid enclosed between two plates past models of a circular disk, an airship hull, aerofoils, etc. Of course, in actual practice, the flow is turbulent in at least part of the wake, owing to the formation of vortices. Two experiments were set up to exhibit these vortices and their effect on the object which caused them.

(4) A demonstration of the formation of vortices behind a pendulum dipping into water was afforded by setting in rotation a bowl of water into which the pendulum dipped (Fig. 1a).

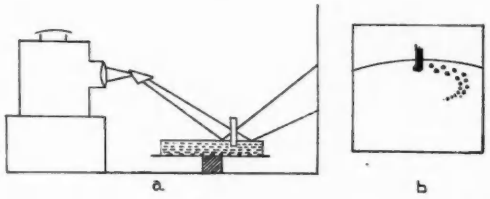

FIG. 1. Method of demonstrating the formation of vortices behind a pendulum dipping into water. *a*, Apparatus. *b*, Sketch of the image on the screen; the eddies appear as shadowy dimples.

The pendulum should be a piece of fairly thin brass tubing about 0.5 in. in diameter and 4 in. long, of which about one-half inch is below the surface of the water. Light from a Point-o-lite lamp was reflected up from the surface of the water on to a screen, where, after the initial disturbance in the swirling water had settled down, the vortices could be plainly observed filing off from the pendulum, which they set into to-and-fro motion if the period of the pendulum had been suitably timed to the eddies (Fig. 1b). The opportunity of pointing out the connection between this phenomenon and "wing flutter" was not neglected. If the velocity V of the stream past the pendulum of diameter D can be measured, the relation[3] governing the frequency n, namely, $V/nD = 5$, can be checked. It was found best to set the water into motion by rotating the bowl to a speed beyond that required and then to stop the bowl, letting the water decelerate gradually and allowing the surface waves to die down before the correct speed was reached.

(5) To make *audible* the effect of these vortices on the obstacle, a piece of elastic was stretched vertically on a small fork and then whirled rapidly round a vertical axis on a small whirling arm. At a suitable speed, the elastic was caused to vibrate audibly under the action of the vortices. This speed can be calculated from the foregoing formula; for example, if the elastic is tuned to a frequency of 100 sec.$^{-1}$, and is 1/8 in. in diameter, the air speed required will be about 5 ft.·sec.$^{-1}$. Under the name of Aeolian tones, these sounds were demonstrated by Strouhal before airplanes were known but their connection with the singing of the struts and stays of aircraft in the wind was pointed out in the lectures, as well as the importance of minimizing the vortex formation which contributes the major part of the drag of aircraft.

(6) Turning then to the heavier-than-air machine, it was now necessary to demonstrate the lift on an aerofoil placed in a wind stream. A wind channel of the closed type is out of the question in a demonstration to a large audience as well as requiring too much space in a lecture theater. Accordingly, an open draft was produced by an air-screw having a disk 3 ft. in diameter, working behind a distributor or honeycomb through which it sucked the air. The model aerofoil was mounted on pivoting arms about 2 ft. long, with a counterpoise at the opposite end, and was placed in front of the distributor (Fig. 2). By means of thumbscrews T, T, at the points of attachment to the balancing arms, the chord of the aerofoil could be set at any desired inclination to the horizontal. Checks prevented the aerofoil from rising too far when lifting. The lift was measured by shifting the counterpoise C on the balance arm. By means

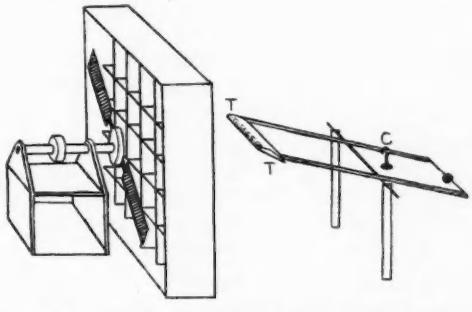

FIG. 2. Apparatus for demonstrating the lift on an aerofoil placed in a wind stream.

[3] Proc. Phys. Soc. **36**, 153 (1924).

of this apparatus was shown (a) the variation of lift with speed relative to the air, (b) the rising and subsequent falling off of lift as the angle of attack was increased. The same apparatus with the pivoting arms set vertically and the aerofoil in a horizontal plane below, served to show the change of drag with speed, the counterbalance being provided this time by a thread passing from the upper end of the balance over a pulley to a scale pan containing suitable weights.

(7) A brief exposition of the Lanchester[4] theory of the aerofoil was next given. To illustrate the idea of a lift being produced by the circulation round the model in a wind stream, a cardboard cylinder in a framework (Fig. 3) was

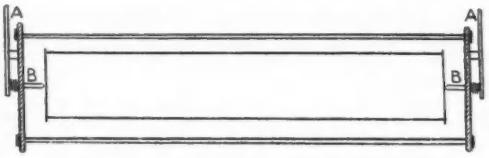

FIG. 3. Cardboard cylinder and framework.

mounted on a balance in front of the fan in place of the aerofoil in Fig. 2. This was set in rotation by a thread wrapped round it and then rapidly pulled off. While the cylinder rotated, it showed a lift or depression according as the cylinder was rotated in the clockwise or counter-clockwise direction. The same cylinder in its framework was held up in a gallery over the lecture bench so that its axis pointed towards the audience; it was again set in rotation by the thread and, when rotating rapidly, was dropped out of its bearings *B*, *B* by the quick releases *A*, *A* at each end (Fig. 3). The cross-force now was evident in the curved trajectory which the cylinder took to reach the ground, instead of the vertical fall of a stationary cylinder. As direct applications of this principle, slides were shown of the rotor ships and rotor planes which have recently been tested in Germany.

(8) A number of demonstrations on the complete aircraft were now staged. For this purpose a small model airplane, about 2 ft. in length and of the type which can be purchased in many model shops, was obtained. The only alteration effected was the provision of ailerons (*A*, *A*, Fig. 4) consisting of small pieces of card fixed to the wing tips by copper wire so that the setting could readily be adjusted by bending the wire, which was at the same time stiff enough to resist the aerodynamic forces which tended to distort it. When this plane was attached to the whirling arm which it drove round under the power of its own wound-up airscrew, a number of features of powered flight could be demonstrated, such as flight in a circular path, nose dive, looping the loop and stalling; each being obtained by a suitable setting of the ailerons and rudder.

In Fig. 4, the rod *BD* is pivoted by a universal joint to the top of the post at *E*. A simple point

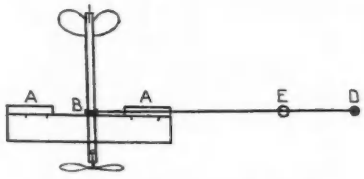

FIG. 4. Model airplane and support.

and cup pivot would serve, provided the arm were weighted at *E* to keep it down on the point during the maneuvers of the model. *D* is a counterpoise and the other end *E* of the rod, which should be at least 1 yd. from *E*, passes through the wooden rod which forms the fuselage of the airplane, so that it can rotate about the axis *BD* only; that is, it is free to elevate but not to yaw. The apparatus is most successful when the inertia is reduced to a minimum. Sometimes the tail ailerons may be removed with advantage when it is desired to make the machine loop the loop. The path round the orbit is in this case usually a cycloid.

The same model plane with the airscrew running free was pivoted at its center of gravity in front of the fan on the balance previously used for the aerofoil, so that the whole plane could pivot about a horizontal axis and at the same time exhibit the lift, if any, on the balance. By setting the ailerons at suitable angles, it was possible to make the plane rise in the draft, stall and slip back again. A continuous spin was also produced by setting the model in fore-and-aft bearings in front of the fan with one elevator up and the other down.

[4] *Aerodynamics*, 1907.

(9) The suggestion was then put forward that the aircraft of the future would be driven by jet reaction and, to illustrate this form of propulsion, a little Hero's engine (2nd cent. B.C.), in which a flask of boiling water is set in continuous rotation by the reaction of a jet of steam issuing from it tangentially, was set going. The experiment may be made more striking if mounted under an evacuated bell jar with the water in the boiler at about 60°C. The water boils under the reduced pressure and the engine rotates, showing that the reaction engine can work equally well in the partial absence of an atmosphere or, indeed, in a vacuum. Finally, a model rocket plane similar to those which have been used on a large scale in Germany was constructed.[5] This was of the tailless, glider type and had a small rocket, of the firework variety but without colored fire, attached to the fuselage, just below the wings (Fig. 5). For safety's sake the flight was made out of the window but it provided a stirring *finale* to the lectures.

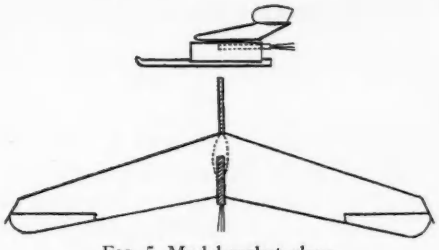

FIG. 5. Model rocket plane.

[5] Sci. Prog. 26, 109 (1931).

An Appliance for Exhibiting Brownian Movement

LOUIS E. JAMES AND W. JAMES LYONS, *Department of Physics, St. Louis University*

A SIMPLE appliance for exhibiting Brownian movement has been constructed and used with satisfaction at St. Louis University for a number of years. Similar appliances are made by several of the apparatus companies but the cheapness and ease of construction of the one described here recommends it for small colleges, and even high schools, where the budget is limited or shop facilities are lacking.

The materials are: a block of wood 7×3.5×2 cm; a piece of glass tubing approximately 1.6 cm in outside diameter and 2 cm long; a piece of felt; sealing wax; and black paper. Fig. 1 shows the assembly. A hole, large enough to take the glass tube, is drilled halfway through the block. Sealing wax to a depth of about 1 cm is placed in the tube to hold it in position. On the wax, while it is still soft, is placed a piece of black paper which covers the whole cross section. A ring of thin, soft felt, having an opening about 0.8 cm in diameter, is glued or shellacked around the upper edge of the tube.

This device is to be used on the stage of a microscope. The objective is brought down to fit snugly into the ring of felt, after smoke has been introduced with a small tube or pipette. The smoke particles may be illuminated very satisfactorily through the side by sunlight reflected from a concave mirror and brought to a focus in the chamber; the mirrors of some microscopes may be removed and used for this purpose. A carbon arc with a lens, has been used as a light-source with success. Cigarette smoke has been found the most satisfactory for examining the motions.

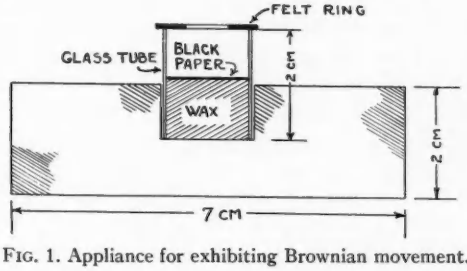

FIG. 1. Appliance for exhibiting Brownian movement.

A Device for Measuring the Contour of the Surface of a Rotating Liquid

WILL C. BAKER, *Physical Laboratory, Queen's University, Kingston, Ontario*

A FLAT cylindrical copper tray, 14 in. in diameter and 1 in. deep, is soldered at three or four points to the turn-table of an old victrola. Vertically above a diameter of this tray and as close to the tray edge as is convenient, is placed a graduated horizontal brass bar (Fig. 1). This bar is not in metallic connection with the motor but is supported on two posts, one equipped with a binding screw, that are fastened to opposite corners of the wooden top of the machine. A carriage that may be slipped along the bar bears a micrometer screw (Fig. 1 (b)). The axis of this screw is vertical and its range of movement is 1 in. The lowest position of the screw is such that its conical point just clears the bottom of the tray and so is protected against damage from the moving bottom. The horizontal scale on the bar and the vertical micrometer scale together constitute a coordinate system from which the contour of a liquid surface may be measured. Alternating current from the lighting system passes through a circuit consisting of a lamp L in series with a small resistance frame (Fig. 1 (a)). Part of this current is led, as shown, through the telephone receiver T to the graduated bar and then back through the tray and motor.

Now, if salty water be put into the tray and the micrometer screw turned down, the telephone will sound at once on contact. The instrument is levelled by the screws at the corners and, as the brass scale runs diagonally across the square top of the box, the scale is easily adjusted so that the micrometer screw-reading at contact with the quiescent liquid is the same at both ends of the bar. In order to determine the point on the horizontal scale which is just above the vertex of the paraboloid of rotating liquid, a small brass "brush" (Fig. 1 (c)) is attached to the side of the tray and the tray is set into slow rotation; readings taken at the two ends of the horizontal bar for contact of the brush with the side of the shaft of the micrometer screw (below the threads) enables one to determine the reading for which the axis of the screw is on the axis of rotation of the tray, and hence the reading which corresponds to the vertex of the paraboloid of rotating liquid.

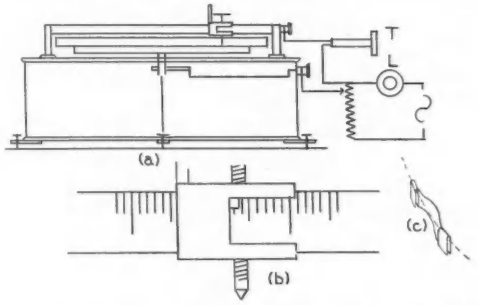

FIG. 1. (a) Diagram of the complete device. (b) Carriage and micrometer screen. (c) Brass "brush."

With the brush removed and the angular speed adjusted until the water rises almost to the top of the tray edge, readings are taken of the contour of the surface. The angular speed of the tray is determined by a stopwatch. It is necessary to rewind the motor from time to time so as to keep its speed constant, a turn or two of the crank after each setting of the micrometer screw being sufficient for this purpose.

Usually, in this laboratory, contours are taken at three speeds spaced as widely as convenient. These are plotted with reference to an origin which is coincident with the vertex of the paraboloid, and smooth curves are drawn. If the student has plotted his vertical displacements to a scale different from that used for the horizontal (and there are advantages in that procedure) he must be careful to note that he has also distorted the angles involved and must read his plot accordingly.

The exercise prescribed includes: (a) the comparison of the direction of the "apparent vertical" (angle between the normal to the curve and the axis of rotation of the tray) as found from the plot with that deduced from theory; (b) the comparison with theory of the mean value of x^2/y, taken from each smooth curve, with $2g/\omega^2$ taken from the corresponding timed, speed of the tray; (c) a proof, from theory, that the surface is equipotential; and (d) the establishment of the relations involved in (b).

An Audible Method of Demonstrating Transient Oscillations in Single and Coupled Tuned Circuits

HERBERT J. REICH, *Department of Electrical Engineering, University of Illinois*

THE teaching of the theory of transient oscillations in single and coupled tuned electrical circuits can be effectively aided by the use of lecture-demonstrations which enable the student to see or hear the important phenomena. For several years the writer has performed a series of such demonstrations and has found them to be of value to the student. Since the apparatus is simple, there is a possibility that it and the methods may be of interest to other teachers of physics and electrical engineering.

The apparatus consists of a two-stage transformer-coupled audiofrequency amplifier, a loudspeaker, a number of low resistance inductance coils and condensers and variable resistances of various sizes. The inductances are made up of No. 18 d. c. c. wire, wound in optimum inductance shape[1] and range in size from 0.1 to 1 h. It is convenient to have two identical coils of each size and to tap the 1-h coils in 0.1-h steps up to 0.5 h.

The simplest demonstration with this apparatus consists in charging a 1- or 2-μf condenser to about 100 volts and discharging it through one of the inductances. The damped oscillations can be readily heard by means of a 0.1-h pickup coil connected to the amplifier and coupled to the oscillating circuit. Because of damping, the pitch cannot always be recognized by a single discharge but, if a number of condensers of different sizes are discharged in succession through the same inductance, the result is quite convincing. The effect of change of inductance upon pitch and of resistance upon damping can also readily be shown. A similar set of experiments can be performed by connecting and disconnecting a low voltage battery to an inductance shunted by a condenser. This demonstration can be made even more spectacular by using the circuit of Fig. 1. The battery circuit is closed periodically by a periodic contactor;[2] and condensers of proper sizes to cover an octave are shunted across the inductance by means of a keyboard. The value of these demonstrations can be increased by pointing out that the two methods of initiating the oscillations, by charging the condenser and by sending current through the inductance, are analogous to starting a pendulum by an initial displacement and by a blow. In the first method the energy is stored electrostatically and in the second, mainly electromagnetically.

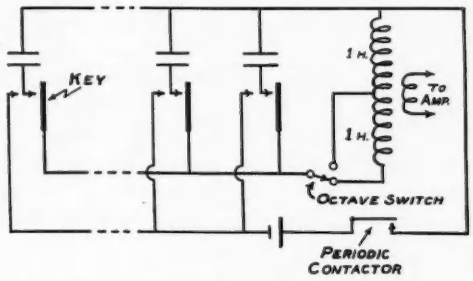

FIG. 1. Method of initiating oscillations by sending current through the inductance.

The production in tuned coupled circuits of two new frequencies f'' and f' which differ from the natural frequencies f_p and f_s of the primary and secondary can be convincingly proved by this apparatus. It may be shown theoretically[3] that the primary and secondary magnetic fields of f'', the higher of these two new frequencies, are 180° out of phase, so that some of the higher frequency flux must come out between the coils at right angles to their common axis, as shown in Fig. 2. The lower frequency fluxes, on the other hand, are in phase and therefore pass through both coils, intersecting the higher frequency flux at right angles at the sides of the coils. Hence, if the pickup coil is placed beside the coupled coils, as shown in Fig. 2, the higher frequency, f'', will be heard when its axis is at

[1] Morgan Brooks and H. M. Turner, *Inductance of Coils*, University of Illinois Bull. 53 (1912).

[2] H. J. Reich, *A Periodic Contactor Operated by a Neon-tube Oscillator*, Rev. Sci. Inst. **2**, 164 (1931); **2**, 234 (1931).

[3] E. L. Chaffee, *Amplitude Relations in Coupled Circuits*, P. I. R. E. **4**, 283 (1916).

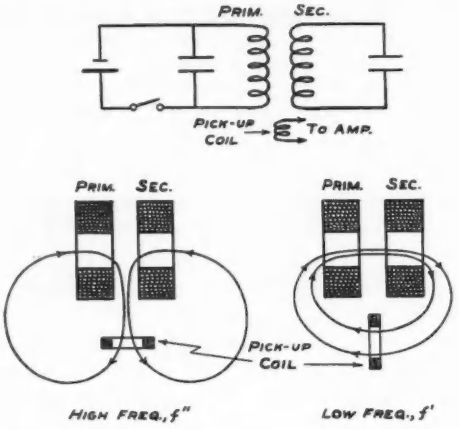

FIG. 2. Production of two new frequencies in tuned coupled circuits.

right angles to the axis of the coupled coils and the lower frequency, f', when the axes are parallel. The natural frequencies, f_p and f_s, of primary and secondary are heard when the secondary and primary condensers, respectively, are disconnected.

Perhaps the most striking demonstration in coupled circuits is obtained when the primary and secondary are tuned to resonance. The higher frequency falls as the coupling is reduced and the lower frequency rises and, if the circuits are resonant, both frequencies approach the natural frequency as the coupling becomes small. With a low natural frequency, such as may be obtained with the 1-h coils, it is possible to hear not only the two new frequencies, f' and f'', but also, with small coupling, the beats between them. The effects of resistance upon primary and secondary currents with various amounts of coupling may also be shown.

Experiments similar to these may be performed at radiofrequencies by using a wave meter to indicate the various component frequencies but the results are not so striking and the technique of performance is considerably more difficult. The audiofrequency demonstrations, in conjunction with a mechanical analogy for coupled electrical circuits,[4] make possible a clear and graphic explanation of the fundamental phenomena of coupled and single electrical circuits.

[4] H. J. Reich, *A Mechanical Analogy for Coupled Electrical Circuits*, Rev. Sci. Inst. **3**, 287 (1932).

A Convenient Projection Electroscope

JOHN J. HEILEMANN, *Randal Morgan Laboratory of Physics, University of Pennsylvania*

FOR lecture-room demonstration of phenomena in which an electroscope is used, the image of the instrument must be projected on a screen. A convenient device for this purpose is shown in Fig. 1. It consists simply of a glass box made to fit into the space usually occupied by the slide carrier. A brass rod, bent as shown and terminating in the usual aluminum foil leaves, passes through a hard rubber plug in the side of the box.

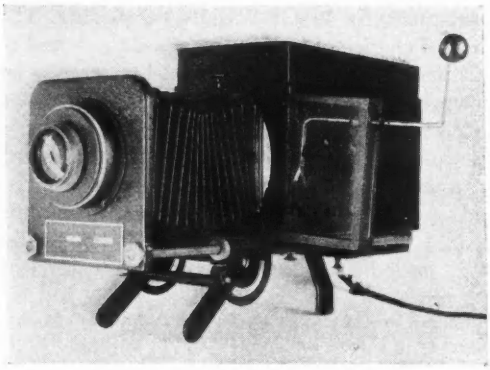

FIG. 1. Projection electroscope.

The Electronichord

NOEL URQUHART, *Department of Physics, Stevens Institute of Technology*

WHEN a string, under tension, is put into vibration, it vibrates not only as a whole, giving its fundamental pitch or first partial tone, but also in halves, thirds, etc., giving the second, third, etc., partial tones. While it is the first partial tone that determines the recognized pitch of a vibrating string, it is the number and intensities of the higher partials that gives the resultant tone its characteristic quality. Melde's experiment shows how a stretched string vibrates in parts forming nodes and loops or standing waves. The *electronichord* is an apparatus for *audibly* demonstrating the partial tones in a vibrating string. It also effectively illustrates Young's law, that no partial tone whose standing wave would have a node at the exciting point can be produced by a string.

The apparatus (Fig. 1) consists of a No. 13 piano wire attached to tuning pins at both ends of a rigid base of maple wood, 2 in. square by 36 in. long. The string passes over metal bridges of 1/8-in. round brass rods which determine its speaking length of 32 in. These bridges are connected by No. 16 copper leads to the primary of a coupling transformer whose secondary is attached to a suitable audio-amplifier and speaker. As it is important that the primary impedance of the coupling transformer should match that of the string, the coupling transformer can be made from an ordinary audiotransformer by replacing its primary by one consisting of ten turns of No. 16 insulated copper wire. The audio-amplifier should have a voltage gain of about 500, the one shown in Fig. 1 being a three-stage resistance-coupled amplifier with two 24 tubes and one 45. The speaker can be of any type whose frequency-response characteristics are good. On the base of the electronichord between the bridges, the anti-nodal (loop) positions of the standing waves for the first eight partials are marked by lines numbered according to the partial or partials represented. On both sides of the string are grooves, that run the entire length of the base, for holding permanent horseshoe magnets of the type commonly used in magnetic speakers. These magnets are to be placed over the string at the several anti-nodal lines. They are eight in number and of the same strength and have their north poles painted black.

With the string tuned to its proper pitch of 256 v.p.s., the apparatus is ready to operate. A single magnet is placed over the string at anti-nodal line 1, the midpoint (Fig. 2a). When the string is plucked near the magnet, the first partial tone is heard from the speaker. What is taking place is Faraday's principle of an e.m.f. being induced in a wire by its motion through a magnetic field. The vibrating string gives rise to an alternating e.m.f. which is amplified and made audible by the speaker. The greater part of this alternating e.m.f. must be of the same frequency as the first partial tone since the magnet is at the

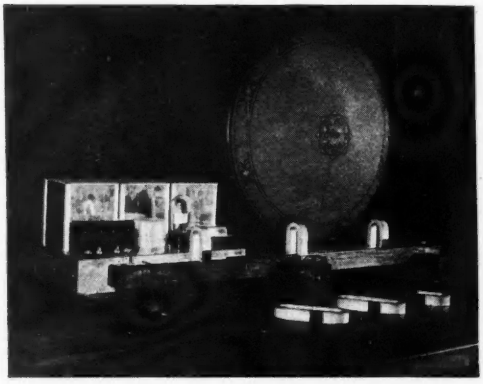

FIG. 1. Apparatus for demonstrating audibly the partial tones in a vibrating string.

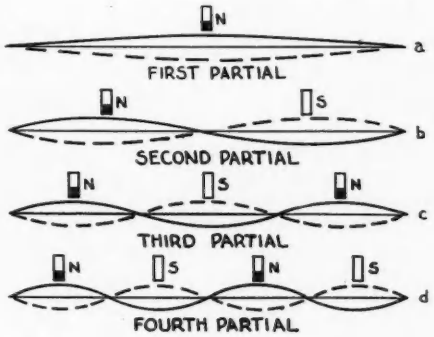

FIG. 2. Methods of obtaining the various partial tones.

anti-nodal point of its standing wave. But the midpoint of the string is also an anti-nodal point for all odd partial tones, so that, by careful attention, the third and even the fifth partial tones can be recognized during the later period of the vibration. If, however, the string is plucked at a nodal point of the standing wave for the third partial tone, its presence is no longer noticeable, thus clearly demonstrating Young's law. The same is true for the fifth partial tone. None of the even partial tones can be heard since the magnet is at a nodal point for all even standing wave forms.

The magnet at the midpoint is now moved along the grooves towards the left to anti-nodal line 2 and a second magnet is placed to the right at the other anti-nodal line 2 with its polarity opposite to that of the first magnet (Fig. 2b). When the string is plucked near one of the magnets, the second partial tone is heard from the speaker. The absence of the first partial tone is readily understood since, its standing wave being entirely above or below the rest position of the string at any instant of time, the induced e.m.f.'s oppose and cancel one another, the polarity of the magnets being opposite. However, for the second partial tone there is a nodal point at the middle of the string and at any instant of time one loop is above and the other loop is below the rest position of the string, so that the induced e.m.f.'s are additive. If the string is plucked at the midpoint, no second partial tone is heard, again illustrating Young's law.

When three magnets are arranged as in Fig. 2c and the string is plucked near one of them, the third partial tone is heard from the speaker. The second partial tone is absent since the magnet at the midpoint is at a nodal point for the second partial's standing wave and the e.m.f.'s induced by the other magnets oppose and cancel each other. The first partial tone is absent since the e.m.f. induced by the middle magnet opposes and cancels those induced by the other magnets (Fig. 2c). If the string is plucked at a nodal point of the standing wave for the third partial tone, then that tone is no longer heard.

By repeating the foregoing procedure the successive higher partial tones are obtained. For selecting any partial tone on the electronichord only the following facts need be kept in mind: (1) The anti-nodal lines are marked with their respective partial numbers, all odd partials having anti-nodal lines at the midpoint of the string. (2) The number of magnets used equals the number of the anti-nodal positions and also the number of the partial tone. (3) Adjacent magnets are of opposite polarity and are equally spaced along the string.

The partial tones obtained with this apparatus compare as to frequency with a set of tuning forks that represent the first eight harmonic tones. By making use of two electronichords, the pure musical intervals that exist between the partial tones can be produced and the existence of beat tones verified. Although the electronichord in its present simple form is an effective and easily manipulated apparatus, possibilities for further development suggest themselves which it is hoped will be realized.

ACCURATE and minute measurement seems to the non-scientific imagination a less lofty and dignified work than looking for something new. But nearly all the grandest discoveries of science have been but the rewards of accurate measurement and patient long-continued labor in the minute sifting of numerical results.—LORD KELVIN, *Report of the British Association for the Advancement of Science* **41**, *91* (*1871*).

Proceedings of the American Association of Physics Teachers

Minutes of the Boston Meeting, December 28–30, 1933

THE third annual meeting of the American Association of Physics Teachers was held in Jefferson Physical Laboratory, Harvard University, and at the Massachusetts Institute of Technology on Thursday, Friday and Saturday, December 28–30. Professor Frederic Palmer, Jr., President, and Professor David L. Webster, Vice-President, presided.

At the Thursday afternoon session, the Association met jointly with the American Physical Society for a symposium on modern physics. The invited papers for the symposium were as follows: *Introduction to the Theory of the Positron*, by G. E. Uhlenbeck, University of Michigan; *The Positron*, by Carl D. Anderson, California Institute of Technology; *The Theory of the Electron and Positive*, by J. R. Oppenheimer, University of California, Berkeley. On Friday evening the Association joined with the Physical Society for dinner at the Parker House. The President of the Physical Society, Doctor Paul D. Foote, presided. The after-dinner speakers were Professor A. H. Compton, Doctor Lyman J. Briggs, Professor Duane Roller, Doctor W. F. G. Swann, and Doctor Karl K. Darrow.

Sessions for the Reading of Papers

Four sessions were devoted to invited and contributed papers. The invited papers were as follows:

1. The Place of Lecture Demonstrations in an Elementary Physics Course—Illustrated by Experiments. N. H. Black, *Harvard University.*

2. Some Effective Lecture-Room Demonstrations. D. C. Miller, *Case School of Applied Science.*

3. A New Outlook for Physics. K. T. Compton, *Massachusetts Institute of Technology.*

4. Experimental Demonstrations in Molecular Physics. Hans Mueller, *Massachusetts Institute of Technology.*

5. Demonstrations of Some Supersonic Phenomena. G. W. Pierce, *Harvard University.*

The attendance at these special programs exceeded two hundred. The wealth of material presented and the techniques illustrated by the speakers delighted the audiences and were extremely helpful to those interested in the teaching of physics. An additional attraction at one of the special meetings was the first showing of the two films, *Sound Waves and their Sources* and *Fundamentals of Acoustics*, the fifth and sixth films in the University of Chicago physical science series.

Contributed papers on a variety of subjects were presented as follows:

1. Study Habits in Elementary Physics. Wilfrid J. Jackson, *Rutgers University.*

2. Classroom and Laboratory Demonstrations: (a) A Lecture-Table Telephotophone; (b) A Demonstration Model for Nuclear Disintegration; (c) Two Novel Surface Tension Experiments. Richard M. Sutton, *Haverford College.*

3. Where Do We Live—Reflections on Physical Units and the Universal Constants. Edwin U. Condon, *Princeton University.* (By title.)

4. Some Experiments for an Intermediate Course in Mechanics. M. H. Trytten and A. G. Worthing, *University of Pittsburgh.*

5. College Transfer Students at the Massachusetts Institute of Technology. Clarence E. Bennett, *Massachusetts Institute of Technology.*

6. Report on Introductory General Courses in Physical Science at the University of Chicago. Harvey B. Lemon, *University of Chicago.*

7. An Almost Forgotten Case of Inelastic Impact. Harvey B. Lemon, *University of Chicago.*

8. A Survey of the Mathematical Skill Used in the Solution of Problems in Five Physics Textbooks. C. J. Lapp, *University of Iowa.*

9. A Research Program in the Teaching of College Physics and Some Preliminary Findings. C. J. Lapp, *University of Iowa.*

10. Actual and Apparent Mathematical Content of College Physics. Robert S. Shaw, *College of the City of New York.*

11. The Nature of B and H and Related Magnetic Quantities. W. H. Michener, *Carnegie Institute of Technology.*

12. The Magnetic Fields B and H—Their Definitions, Nature and Use. F. W. Warburton, *University of Kentucky.*

13. Limiting Velocity—A Neglected Topic in General Physics. G. K. Daghlian, *Connecticut College.*

14. The Relationship between College Chemistry and College Physics as Revealed by a Cooperative Status-Study of Sixty-eight Institutions. Edwin Morrison, *Michigan State College of Agriculture and Applied Science.*

Meetings of the Executive Committee

The executive committee held meetings on Thursday evening, December 29, and Friday afternoon and evening, December 30. Members of the committee who were present were Frederic Palmer, Jr., David L. Webster, Thomas D. Cope, A. G. Worthing and F. K. Richtmyer. Others who were present at the request of the executive committee were D. W. Cornelius, member-elect, Duane Roller, Editor of the journal, and M. N. States, who acted as secretary in the absence of Professor Webb.

New Chapters. Petitions for regional chapters of the Association in Kentucky and in Oregon were unanimously approved. The secretary was instructed to notify each of these chapters that it is entitled to have a representative on the executive committee if it has fifteen or more Association members on its rolls. The Kentucky chapter was commended for having submitted a constitution under which it will operate. It was recommended that other chapters be requested to furnish similar constitutions. An informal petition for a chapter in the Philippine Islands was read and it was voted that the petition should be regarded as approved as soon as the group meets the constitutional requirements as regards number of Association members.

Procedure for electing officers. The nominating committee for 1934 was appointed as follows: W. L. Cheney, George Washington University, T. D. Cope, University of Pennsylvania, R. L. Petry, University of the South, W. Weniger, Oregon State College. The executive committee voted that for the forthcoming election of officers in 1934 members are to be furnished with both a ballot and an envelope, with instructions that only the envelope is to be signed.

President Palmer was reelected for a three-year period as a representative on the governing board of the American Institute of Physics.

Membership. It was recommended that the following action be taken with regard to eligibility for membership in the Association: Art. III, Sec. 2(b) of the constitution shall be interpreted to mean that all teachers of physics who have professional qualifications equivalent to those required of teachers of college physics are eligible for membership.

It was recommended that the dues for 1934 remain at three dollars.

All applications for membership which were received during the year 1933 were approved. It was agreed that the rule requiring two sponsors for each member-elect should be rigidly adhered to.

The Journal. Upon the recommendations of the Editor and President Palmer, G. P. Harnwell, Princeton University, was appointed as an associate editor of *The American Physics Teacher.*

The policy was adopted of refusing to furnish commercial concerns with lists of members and of subscribers to the journal. The president appointed a committee consisting of H. L. Dodge, Wm. S. Webb, and Duane Roller to consider the question of using the columns of the journal in aiding physics teachers to transfer from one position to another. A letter from Dr. Henry A. Barton, director of the American Institute of Physics, was read, which stated that the NRA printers' code will probably result in an increase of 20 percent in the cost of publication of the journal for 1934. Since the committee felt it to be unwise to increase the Association dues or the subscription price at this time, and in view of the fact that the treasurer reported that the present treasury balance would be needed to cover amounts due to the Institute of Physics for journal expenses in 1933, it was obvious that an effort would have to be made to increase the membership. Although no official action was taken, the president was requested to appoint a committee to formulate plans for a membership campaign.

Upon the suggestion of President Palmer, approval was given to the appointment of committees to study the feasibility of sponsoring the publication of an encyclopedia of demonstration lectures and to consider means for stimulating interest in physics as a cultural subject.

The Annual Business Meeting

The regular annual business meeting of the Association was held on Saturday afternoon, December 30 in Jefferson Physical Laboratory, Harvard University.

President Palmer commented briefly on the progress of the Association during the past year. He stressed the necessity for increasing the income of the Association for 1934, primarily because of the increasing cost of publication of *The American Physics Teacher*, and asked the cooperation of everyone in making a success of the proposed membership campaign.

President Palmer also explained the action of the executive committee in interpreting Art. III, Sec. 2(b) of the constitution to mean that all teachers of physics who have professional qualifications equivalent to those required of teachers of college physics are eligible for membership. He stated that this interpretation would permit secondary-school teachers who have such qualifications and training to become members. A motion was made by Professor Cope and seconded by Professor Cornelius that this action of the committee be ratified. After considerable discussion the action was formally ratified.

The acting secretary reported the following election for 1934:

President.....Frederic Palmer, Jr., *Haverford College*
Vice-President...David L. Webster, *Stanford University*
Members of the Executive Committee
D. W. Cornelius, *University of Chattanooga*
L. W. Taylor, *Oberlin College.*

The report of the treasurer for the year ending December 15, 1933, was read and approved, subject to audit. President Palmer appointed K. K. Smith and L. I. Bockstahler to audit the report.

Upon the motion of Marsh W. White, discussed and unanimously passed, the president appointed a committee on units and measurements as follows: W. H. Michener, *chairman*, F. W. Warburton, N. C. Little, D. L. Webster.

Reports were given by C. J. Lapp, chairman of the committee on tests, and David L. Webster, chairman of the recently appointed committee on the teaching of premedical physics. Professor Lapp reported that 22 institutions had cooperated in 1933 in administering the standard tests prepared by the tests committee. The results of these preliminary examinations were so satisfactory that 130 colleges and universities have already signified their intention of cooperating with the committee in 1934.

M. N. States, *Acting Secretary*

Annual Report of the Treasurer

Balance brought forward from December 31, 1932 [see *American Physics Teacher* **1**, 25 (1933)]		$ 960.78
Cash Received		
1933—Dues $3.00 received from 422 members	$1266.00	
Dues of $2.00 received from 42 members	84.00	
Additional dues of $1.00 received from 9 members who had paid $2.00 dues in 1932 for 1933	9.00	
1934—Dues received from four members	12.00	
Total Dues Collected	$1371.00	
Exchange received from members	$ 7.40	
Refund from W. S. Webb of part of travelling expenses allowed the secretary to the Atlantic City meeting, 1932	36.90	
Total Cash Received	$1415.30	1415.30
Total money deposited	$1533.55	
Checks returned from banking holiday and redeposited	118.25	118.25
	$1415.30	
TOTAL MONEY IN BANK		$2494.33

Disbursements[1]	$1111.68	
Services and exchange charges	21.18	
	$1132.86	
Checks returned after banking holiday (redeposited)	118.25	
TOTAL DISBURSEMENTS	$1251.11	1251.11
BALANCE ON HAND,[2] December 15, 1933		$1243.22

PAUL E. KLOPSTEG, *Treasurer*

January 4, 1934

This will certify that we have examined the vouchers, checks and bank statements of the treasurer of the American Association of Physics Teachers and find the report of December 15, 1933 to be correct.

LESTER I. BOCKSTAHLER
K. K. SMITH
Auditing Committee

[1] *Itemized List of Disbursements:* Neely Printing Co., $9.50; John R. Humphrey, $26.20; The Kentucky Kernel, $68.25; Low's Letter Service, $3.92; Transcript Enterprise Publishing Co., $22.60; Science Press, $8.04; traveling expenses for W. S. Webb and Duane Roller, $75.71; postage, $65.59; secretarial services, $72.45; American Institute of Physics, $750.00; posters, $1.50; Western Union Telegraph Co., $6.52; supplies for editorial office, $1.40. Total $1111.68.

[2] Most of this balance will be needed to cover amounts due the American Institute of Physics for journal expenses in 1933.

Report of the Committee on Differentiation in First-Year Courses

WHILE the Committee feels that this is not a suitable time for a final report, the Chairman is presenting herewith the results of an analysis, as regards physics courses, of some 119 college and university catalogs. These catalogs depict the situation as it existed perhaps two years ago, on the average, when educational conditions were more nearly normal than they are at the present time.

The first result of this survey is the fact that of the 119 institutions studied—representing at least all the major colleges and universities of the country—64 give first-year college physics with no mathematical prerequisite specified. In perhaps a quarter of these cases, however, the student must have had high-school physics or the equivalent course as given in the college or university. Twenty-eight institutions offer such a secondary course but not, in general, for college credit.

In 11 institutions college algebra is prerequisite for the general physics course and in 30, at least some trigonometry is required. In 11 cases still more mathematical preparation is specified, and this sometimes includes calculus.

Only one institution seems to offer a general course without laboratory. Seven schools give a second general course for those who can profit by a more fundamental treatment. In 9 colleges the general course is made to supply the needs of engineering students by adding special problem sections. In one or two cases there are special sections for engineering and premedical students. In some cases an extra class section is recommended for those who have not had high-school physics. One institution—a coeducational one at that—offers a course in "Physics for Women."

Of the 119 institutions studied 53 offer special physics courses for engineering students. Of these, 32 specify trigonometry as a prerequisite, 9 analytic geometry and 12 calculus.

Sixteen survey courses and 15 home economics courses form the next largest numbers of special courses offered. Only 13 special premedical physics courses are given notwithstanding that premedical students form one of the largest groups taking physics. The idea suggested in the

preliminary report of last year [*Am. Phys. Teacher* **1**, 51 (1933)] that the premedical students ought to be able to take the same medicine as anyone else is borne out by these facts. Where there is a special premedical course it is usually intimated that this is more difficult than the general one. In one or two cases calculus is required.

There are 10 special courses for agricultural students and this is the last large group. Some of the other groups given special courses, but only one or two in each case, are physical education, predental, forestry, textile school and business students.

As a general rule the amount of differentiation is proportional to the size of the institution and one gains the impression that such differentiation has, in the majority of cases, been a matter of gradual growth and expansion to meet fairly definite demands. The writer does not feel that the situation calls for any definite recommendations, but the survey as here presented may be of service as indicating the general trend. This trend is at least worthy of consideration by any department or institution intending to make changes in its curriculum.

L. R. INGERSOLL, *Chairman*

Teaching Aids

Readers are urged to communicate to the Editor any information which they may have concerning charts, exhibits, demonstration devices, films, slides, bulletins, reprints or other teaching aids that can be obtained free of charge or at a nominal cost from educational agencies and industrial concerns.

MOTION PICTURES

A Modern Zeus. 1 reel, sound, 35 mm. Film No. S-2288. General Electric Co., Visual Instruction Section, 1 River Road, Schenectady, N. Y. Loaned gratis.

Demonstrates the production of artificial lightning by the 10,000,000-volt generator in the high voltage laboratory at Pittsfield. This apparatus is used in studying the effects of lightning on electric power systems.

Motion Pictures. Pp. 10. Figs. 17. Bul. GES-402C. General Electric Co., Visual Instruction Section, Schenectady, N. Y. Gratis.

This bulletin describes 34 sound and 55 silent films that may be borrowed without charge, except for the cost of transportation. Many of these films have great instructional value. In one sound film, for example, William Bragg reenacts Faraday's early experiments in magnetism with Faraday's original apparatus; in another, Ernest Rutherford relates and demonstrates his theories of the constitution and transformation of the elements.

Motion Picture Films of the United States Bureau of Mines. Pp. 23. U. S. Bureau of Mines Experiment Station, Pittsburgh, Pa. Gratis.

This pamphlet describes about 60 silent films that may be borrowed without charge, except for the cost of transportation, from various subdistributing centers of the Bureau of Mines. All films are available in the 35-mm width, and many are also obtainable in the 16-mm size. The cost of production of the films is paid by cooperating industrial concerns but the pictures are free from direct advertising material. Among the available subjects are: Water power (2 reels), Transportation (2 reels), Story of a gasoline motor (3 reels), Story of a storage battery (2 reels), Story of power (3 reels), Construction, operation and care of the internal combustion engine (3 reels).

LITERATURE

U. S. Government Publications Useful to Teachers of Science. MINA M. LANGVICK, Senior Specialist in Elementary School Curriculum, and VICTOR H. NOLL, Specialist in School Organization. Pp. 20. Cir. No. 48, mimeographed. U. S. Office of Education, Washington, 1932. Free.

An annotated list of publications which contain subject matter suitable for use in instruction below the college level.

Demonstrating the Gyroscope. Pp. 24. Figs. 12. (Paper cover.) Sperry Gyroscope Co., Brooklyn. Gratis.

Explains how to use a hand-operated model gyroscope in demonstrating the gyro-stabilizer, the gyro-compass, the artificial horizon and the directional gyro.

The Ring Method for Surface and Interfacial Tensions with the Cenco-duNoüy Tensiometers. Pp. 20. Figs. 6. Mimeographed, paper cover. Bul. 101, Central Scientific Co., Chicago. Gratis.

Gives the theory involved, a description of the apparatus used, directions for making measurements, precautions to be observed, and a complete bibliography of papers relating to the ring method.

Brief Notices of Recent Publications

Elementary Textbooks

Answers for Problems in Introductory Physics. L. Grant Hector, Professor of Physics, University of Buffalo. Pp. 8. American Book Co., New York. Price 8 cts. Gives the answers to the quantitative problems which appear in the author's *Introductory Physics*.

Textbook of College Physics. C. A. Chant, Professor of Astrophysics, and E. F. Burton, Head of the Department of Physics, University of Toronto. Pp. 541+xiv. Figs. 575. Henry Holt and Co., New York. Price $3.25. An elementary textbook of the conventional type, for students who have not had high school physics. Topics that are somewhat specialized or difficult are printed in small type.

Intermediate and Advanced Textbooks

Physical Mechanics, Robert Bruce Lindsay, Associate Professor of Theoretical Physics in Brown University. Pp. 436+x. Figs. 171. D. Van Nostrand Co., New York, 1933. Price $4.00. This textbook for students who have had one year of general physics and the simple elements of calculus is characterized by its logical presentation of the fundamental concepts of mechanics and its recognition of the needs of the students of present-day physics. Elementary vector methods are introduced and there are many problems. Chapters on constrained motion, aggregates of particles, deformable bodies and wave motion, and fluids are included. The book is one of a series edited by Professor Leigh Page.

Experimental Atomic Physics. G. P. Harnwell, Assistant Professor of Physics, Princeton University, and J. J. Livingood, Research Associate, The University of California. Pp. 472+xiii. Figs. 175. McGraw-Hill Book Company, New York, 1933. Price $5.00. A textbook for an experimental course for seniors and first-year graduate students. It is not a laboratory manual of the traditional type but a presentation of the subject of atomic physics from the experimental point of view. Because of its detailed descriptions of the techniques for determining practically all of the important quantities of atomic physics, the book will doubtless prove to be exceedingly useful to the beginner in experimental research. There are many references to original sources.

Miscellaneous

The Universe of Light. William Bragg, Fullerian Professor in the Royal Institution of Great Britain. Pp. 283+x. Figs. 110. Plates 26. The Macmillan Co., New York, 1933. Price $3.50. This charmingly written and beautifully illustrated book is an outgrowth of the author's Christmas Lectures of 1931 at the Royal Institution. It is essentially an elementary survey of the subject of light—of the simple properties of light, vision, colors and their origin, colors of the sky, polarization, x-rays, and the rival theories. Unlike many of the recent books prepared for popular consumption, it is refreshingly free from metaphysical speculation. In keeping with the fine tradition begun by Faraday, who gave the Christmas Lectures for fourteen years, the treatment is based upon and amplified by a large number of interesting and fundamental experiments. Many of the illustrations, some of them in natural colors, are taken from laboratory photographs. Teachers will find the book stimulating. Every beginner in physics should have access to it.

The Science of Radiology. Otto Glasser, Editor, Director of the Radiation Research Department, Cleveland Clinic Foundation. Pp. 450+xiii. Figs. 108. Charles C. Thomas, Springfield, Illinois. Price $4.50. An important, comprehensive presentation of the history and present development of radiology, prepared under the direction of the American Congress of Radiology by 26 specialists in biology, physical science and medicine. Among the physical scientists who contributed chapters are: D. L. Webster, roentgen-ray physics; E. C. Jerman, apparatus; W. D. Coolidge and E. E. Charlton, tubes; J. C. Hudson, dosimetry; G. Failla and E. H. Quimby, radium physics and dosimetry; L. S. Taylor, roentgen-ray protection; G. L. Clark, industrial radiology; M. Luckiesh, visible, ultraviolet and infrared therapy; A. H. Compton, cosmic rays. The book is well printed, and the paper and binding are of good quality.

Number: The Language of Science. Tobias Dantzig, Professor of Mathematics, University of Maryland, and Lecturer on Mathematical Physics, U. S. Bureau of Standards. Second edition. Pp. 255+vii. Figs. and plates 22. The Macmillan Co., New York, 1933. Price $2.50. A book for the intelligent layman on the evolution of the number concept, and the relation of mathematics to science. The revision has been confined mainly to the correction of errors.

Abbreviations for Scientific and Engineering Terms. Sectional Committee on Scientific and Engineering Symbols and Abbreviations. Pp. 6. American Standards Association, New York, 1932. Price $.40. (Paper cover.) Gives rules for abbreviation and lists the abbreviations of about 260 terms. The use in text of exponents for the abbreviations of square and cube and for terms involving "per" is not recommended. Periods are generally omitted, an exception being the abbreviation for *inch*. The price of the pamphlet is excessive.

Code for Protection Against Lightning. Parts I, II and III. Revised edition. Pp. 93+x. Figs. 4. Bureau of Standards Handbook No. 17, Government Printing Office, Washington. Price $.15. (Paper cover.) Gives detailed directions for the protection of persons and of various types of structures against lightning. In a 34-page appendix, the various types and characteristics of lightning are

described and modern theories are explained. A useful bibliography is included.

The Laboratory Workshop. E. H. DUCKWORTH, Inspector of Science and Technical Education, Colonial Service, Nigeria, and R. HARRIES, Imperial College of Science and Technology, London. Pp. 246+xi. Figs. and plates, 436. G. Bell and Sons, London, 1933. Price 10/-net. This valuable practical guide to the equipment of a laboratory workshop, the use of tools and materials, and apparatus making is intended to assist school-science teachers in making the workshop a useful and vitalizing part of their equipment. Two chapters are devoted to tested plans for the construction of novel demonstration apparatus. Elaborate, expensive shop equipment is not required.

The Sound Motion Picture in Science Teaching. PHILLIP JUSTIN RUDON, Graduate School of Education, Harvard University. Pp. 236+xi. Figs. 8. Tables 21. Harvard University Press, Cambridge, 1933. Price $2.50. Reports the results of a carefully-made investigation of the effectiveness of the sound motion picture in the teaching of ninth grade physiography and biology. The study was financed by the Carnegie Foundation for the Advancement of Teaching. Among the interesting results given are the conclusions that, in terms of immediate student achievement, the teaching technique employing films was 20.5 percent more effective from the instructional standpoint than was the unaided presentation and, in terms of retention, the film technique was 38.5 percent more effective. There was no evidence that the film technique encouraged superficial thinking, dulled the imagination, or taught unrelated facts at the expense of the ability to think.

Articles to Appear in Forthcoming Issues

Among the articles and contributions which will appear in early issues of *The American Physics Teacher* are:

RÔLE OF POSITRONS AND NEUTRONS IN MODERN PHYSICS
W. V. Houston

WHERE DO WE LIVE? REFLECTIONS ON PHYSICAL UNITS AND THE UNIVERSAL CONSTANTS
E. U. Condon

NEW PHYSICS LABORATORY AT THE UNIVERSITY OF TEXAS
S. Leroy Brown

ELLIPTIC POLARIZATION OF LIGHT
W. W. Sleator

LANTERN SLIDES FOR ILLUSTRATING LECTURES
W. E. Forsythe

LABORATORY COURSE IN ATOMIC PHYSICS
O. Oldenberg and F. F. Rieke

CONTENT OF THE COLLEGE PHYSICS COURSE
A. E. Caswell

PHYSICS IN THE COMMERCE CURRICULUM
C. H. Dwight

FLAME TEMPERATURE MEASUREMENTS BY THE LINE REVERSAL METHOD FOR SECOND YEAR LABORATORY STUDENTS
Geo. W. Sherman, Jr.

CONVENIENT AND EFFECTIVE METHOD OF CHARGING ELECTROSCOPES
J. A. Culler

EXPERIMENTAL WIND TUNNEL
S. R. Williams

ELECTROSTATIC VOLTMETER
Milton Y. Warner

EQUIPOTENTIAL LINES IN A CONDUCTING SHEET
V. E. Eaton

WORKING MODEL FOR SHOWING NUCLEAR DISINTEGRATIONS
Richard M. Sutton

ON THE FORCES BETWEEN MAGNETS AND THE LAW OF INVERSE SQUARES
Eric J. Irons

DEMONSTRATIONS OF THE REMOVAL OF IONS FROM CONVECTION CURRENTS
John J. Heilemann

ABSTRACTS

Abstractors for This Number: F. W. Crawford, R. J. Havighurst, F. E. Knowles, Duane Roller, G. A. Van Lear, Jr.

Apparatus, Demonstrations and Laboratory Practice

1. Classification of bridge methods of measuring impedances. John G. Ferguson; *Bell. Sys. Tech. J.* **12**, 452-468, Oct., 1933. An analysis is made of the requirements for satisfactory operation of the simple four-arm bridge when used for impedance measurements. The various forms of bridges are classified into two major types called the ratio-arm type and the product-arm type, based on the location of the fixed impedance arms in the bridge. These two types are subdivided further, based on the phase relation which exists between the fixed arm impedances. Eight practical forms of bridges are given, three of them being duplicate forms from the standpoint of the method of measuring impedance. These bridges together allow the measurement of any type of impedance in terms of practically any type of adjustable standard. The use of partial substitution methods and of resonance methods with these bridges is discussed and several methods of operation are described which show their flexibility in the measurement of impedance. (The author.) D. R.

2. A new idea in projecting microscopic slides. Wm. S. Green, Jr.; *Ed. Screen* **12**, 217–218, Oct., 1933. A microprojector is devised from an ordinary projection lantern and a microscope. The barrel of the microscope is tilted to a horizontal position, the eyepiece removed and a low power objective of the microscope becomes the projection lens for small objects placed on the stage of the microscope. The projection lantern, which is placed in line with the optic axis of the microscope objective, furnishes sufficient illumination for classroom projection of the growth of crystals. Some discussion of the technique for making permanent microscope slides is included. F. W. C.

3. A graphical device for obtaining $(a^2 + b^2)^{\frac{1}{2}}$. E. C. Schurch; *Elec. Eng.* **52**, 799–800, Nov., 1933. An easily constructed device (Fig. 1) is described for calculating $(a^2 \pm b^2)^{\frac{1}{2}}$ by only two settings. It can be used to solve, with slide rule accuracy, many electrical problems and to obtain trigonometric functions without reference to tables. The device measures 8.75×12.25 in.; the movable members are made of heavy celluloid. The T-square member carries a scale which represents one side of a triangle, or reactive volt-amperes, or reactance. The fixed horizontal scale represents the other side of the triangle, or watts, or resistance. The hinged member represents the hypotenuse of the triangle, or volt-amperes, or impedance. The three scales are identical. To obtain $(a^2+b^2)^{\frac{1}{2}}$, the reference line of the T-square member is set to the value of a on the fixed horizontal scale. The hinged member is rotated until its reference line crosses that of the T-square member at the value of b. The result is read on the hinged member at b. D. R.

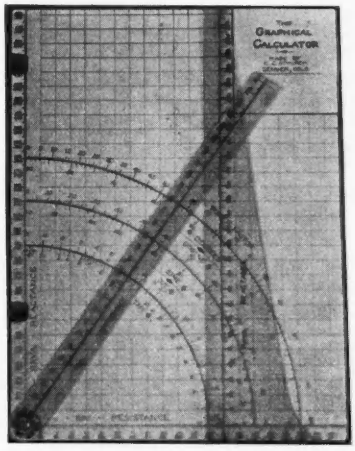

Fig. 1.

4. Ground glass junctions. Harlan L. Baumbach; *Ind. and Eng. Chem.* Anal. Ed. **5**, 349, Sept., 1933. A device for making tight ground-glass junctions is described. Sheet copper 0.75 mm thick is cut as shown in Fig. 1, bent in the form of a hollow cone, and soldered end to end. Standard dimensions call for an increase of 0.15 cm in diameter for every centimeter measured along the axis of the cone. The cone can be mounted by means of a one-holed rubber stopper and a 5-mm wooden dowel placed in the chuck of the lathe or drill press. The inside of the cone is used for the

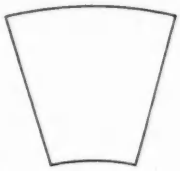

FIG. 1.

grinding of the glass taper and the outside for the grinding of the glass socket, thus insuring the same slope for the taper and socket. Turpentine or water is applied either to the copper or to the glass and powdered silicon carbide is added. D. R.

5. Apparatus for filling large closed-end manometers. ANGUS E. CAMERON; *Ind. and Eng. Chem.*, Anal. Ed. **5**, 419, Nov., 1933. The ordinary method of filling a closed-end manometer and boiling out gases from the mercury during evacuation is attended with danger of breakage when the manometer is of large bore and sufficient length to enable

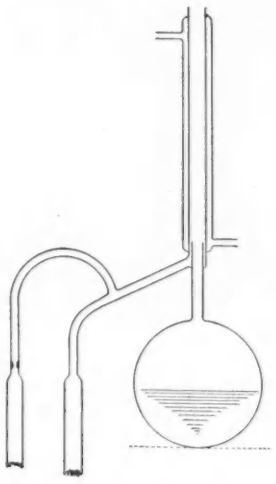

FIG. 1.

one to read pressures over a range of one atmosphere. Distillation of mercury into the manometer through a side tube permits trapping of gas or vapor below the wall of mercury vapor in the tube. The apparatus shown in Fig. 1 overcomes both difficulties. Clean mercury is placed in the bulb and the upper end of the short water-jacketed condenser sealed to a good oil pump. The system is evacuated, the manometer flamed, and the mercury in the bulb then boiled. The mercury vapor condensing above the jet passes into the manometer tube and water vapor and gas pass up through the condenser. When sufficient mercury has accumulated in the manometer, the closed end is sealed off at the strictured portion. D. R.

6. Blast lamp from Bunsen burner. ROSS A. BAKER; *J. Chem. Ed.* **10**, 745, Dec., 1933. To provide glass-blowing facilities for large numbers of students at slight expense, an appliance has been devised to convert an ordinary Bunsen burner into a blast lamp. It consists essentially of a blast head (Fig. 1) which slips over the top of the burner. "The

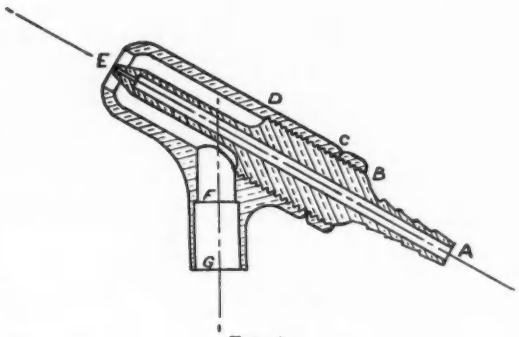

FIG. 1.

head carries within it a tube through which air or oxygen may be supplied from any convenient source, varying from a pump to a rubber balloon. It is most readily constructed of glass, but metal is recommended for durability. In the latter case it is advisable first to cast a slug of brass or aluminum of approximately the shape shown in Fig. 1 and having overall dimensions as follows: length *C–E*, 2⅜″; diameter at *C*, 13/16″; diameter at *G*, 9/16″. A 19/32″ hole is drilled in the slug from *C* to within about ⅛″ of *E*, and a 7/16″ hole is drilled to this point through the end at *E*, thus producing a restricted gas outlet. A 7/16″ hole is drilled from *G* to *F* (a distance of about 11/16″), and a ⅜″ hole from this point to the interior of the tube. The resulting shoulder seats the Bunsen burner top. A ⅝″, 0.27 U.S.F. thread is then cut inside from *C* to *D*. The air tube is adapted from a piece of 11/16″ rod as follows. (1) A 3/16″ hole is drilled from *A* to within ¼″ of *E*, and a 3/64″ hole to this point from *E*. (2) The outside diameter from *E* to *D* is then turned down approximately ¼″ with a stream-line tip at *E*. (3) A ⅝″, 0.27 U.S.F. thread is cut from *D* to *B* (length, approximately 1⅛″); this comparatively long thread permits convenient adjustment of the air tip. (4) A regulation hose tip is turned on the portion *B–A*, with outside diameter of ¼″ at *A*. The locknut, *B–C*, is made by cutting a narrow collar from a piece of threaded tubing." D. R.

7. A simple substitute for a micrometer eyepiece. H. E. WATSON; *J. Sci. Inst.* **10**, 225–226, July, 1933. The inexpensive and easily made device shown in Fig. 1 may be used in work where the precision given by a micrometer eyepiece is unnecessary, but the accuracy given by estimating the fractional parts of a division is insufficient. Among other uses it is of value for instruction when students experience difficulty in estimating fractions of a scale division. "The method of construction is simple. To the elevating screw *A* a nut *B* is fitted with a pointer attached; the nut

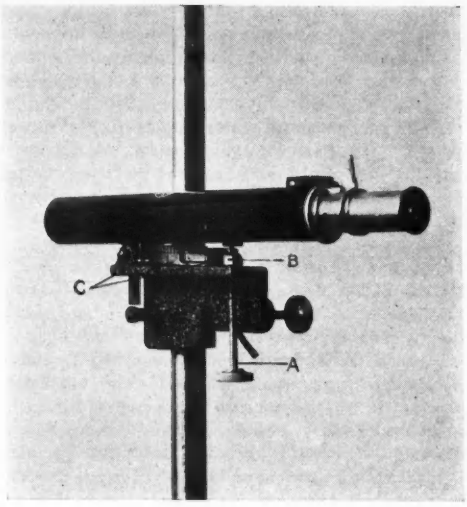

FIG. 1.

should not be too tight and yet not loose enough to shake. The pointer moves across a cylindrical scale, the axis of which coincides with the axis of the screw A, stops C are fitted to the ends of the scale, and the divisions are of such a length that each corresponds to 0.1 mm on the scale to be read. A separate scale is necessary for each distance of the telescope from the object, but as in practice the instrument can generally be used at a constant distance, one scale usually suffices. In the example shown the pointer is 62 mm long and each scale division is 3 mm, the range covered being 2 mm of the object scale to be read. To read a manometer, for example, the whole telescope is moved to the approximately correct position and the cross wire set on the scale division above the meniscus; the pointer is pushed against the right-hand stop and the screw turned until the cross wire coincides with the mercury surface. The fraction of a millimeter is then given by the distance of the pointer from the central division. With the telescope used, which was not altered in any way, readings were quite reliable to 0.05 mm, . . . " D. R.

8. Making a small compressor. ORLIN D. TRAPP; *Pop. Mech.* **60**, 943–944, Dec., 1933. The parts needed for this inexpensive, home-made air compressor are a ¼-hp. electric motor, a small compression tank and an air compressor. The compression tank is made of a pipe nipple about 10 in. long and 2.5 in. in diameter, closed at the ends with caps into which the gauge and connecting devices are set. The pump is to be gotten from an autowrecking yard and is of the type used on automobiles a few years ago. Saw off the parts not needed so as to keep the bearing intact with the crank case. Use a V-belting with a 1.5- or 2-in. pulley on the motor and 6- or 7-in. pulley on the pump. Instructions are given for mounting and oiling. This compressor should be useful for experiments in sound or on the density of air, or with a spray gun. F. E. K.

9. Cements for modeling purposes. ANON.; *Pop. Mech.* **61**, 150–151, Jan., 1934. Two grades of strong and durable cement for molding small objects, for filling cracks in marble and stoneware and for cementing metal, glass or wood parts are described. Thoroughly mix zinc oxide, 12 oz., and powdered calcined magnesia, ¼ oz.; pulverize each ingredient as finely as possible. The mixture may be stored indefinitely in a tightly stoppered bottle. At the time of use work the desired amount into a stiff paste with sirupy phosphoric acid. This is the type of cement used by dentists; it sets quickly, is water proof and can be polished. A less expensive cement consists of finely powdered glass, ½ oz., silicic acid, 1 oz., and zinc oxide, 20 oz., mixed thoroughly and stored in a tightly corked bottle; to use, work into a sirupy solution by adding a small amount of distilled water to dry zinc chloride. A still cheaper cement may be made from finely powdered asbestos and good varnish. F. E. K.

10. Working in glass. RAYMOND BARKULOO; *Pop. Mech.* **61**, 312–315, Feb., 1934. Gives instructions for making various kinds of cuts in glass and for cutting squares and circular openings. The cutter should be run over the glass but once. A fine, clear, continuous cut is to be desired; it need not be deep. Tapping to start the crack is made from the underside. The crack should be continuous before pressure is applied to make the final break. Irregular shapes may be cut by scratching around a pattern of ¼-in. plywood. After the scratching is completed and a complete crack has been formed much of the surplus glass should be removed by straight cutting before the final form is finished. In cutting out squares or rectangles the scratching is not made quite to the corners but the cracks which are started at the midpoint of a side are made to reach to the corner. To bore a hole, make a putty dam about the place where the hole is desired, and fill it with turpentine to lubricate the drill; turn the glass over as soon as the tip goes through. The drill consists of the end of a file formed into a triangular shape. Other directions are given. F. E. K.

11. Permalloy filings for mapping magnetic fields. ARTHUR L. FOLEY; *Proc. Ind. Acad. Sci.* **42**, 163–164, 1933. In mapping magnetic fields by means of iron filings the field at a short distance from a weak magnet will not be strong enough to orient the filings. The orientation may be produced by the use of a strong magnet but in that case the field immediately about the magnet is so strong that the filings fly toward and cling to the magnet, leaving a space more or less free from any filings. The difficulty can be partially overcome by using filings of permalloy. The susceptibility of permalloy is far greater than that of iron in weak fields, and is considerably less in strong fields. As a consequence permalloy filings will orient themselves farther from a magnet than will iron filings, and they will not be drawn toward the magnet quite so strongly in the region immediately about it. Fig. 1 shows a field mapped with permalloy filings. Hard rubber and copper do not affect the field appreciably, the filings being lined up on the inside of disks of these materials just as they would be if the disks were absent. The iron disk bunches the lines of

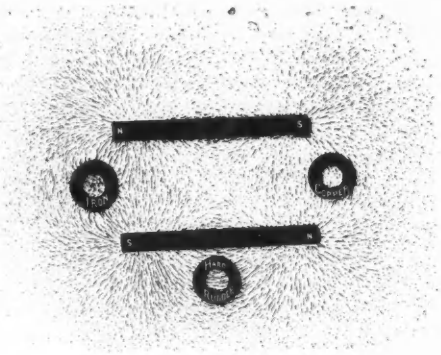

FIG. 1.

force and there is no field inside; the shielding action of iron is clearly shown. Permalloy being rather soft is not readily filed; a rather coarse bastard cut file gives best results. To overcome the bright metallic luster of the filings so as to make the lines of force stand out more conspicuously, place them in a small beaker, wet them with India ink, and stir them occasionally while they are drying over a radiator.

D. R.

12. Silk cellophane for lantern slides. F. F. YONKMAN; *Science* **77**, 218, Feb. 24, 1933. Special duPont No. 300 white silk Cellophane takes ink directly from the typewriter ribbon without smudging. Its cost is less than one cent per slide. D. R.

13. A simple method for the determination of c_p for gases. H. ZEISE; *Zeits. f. math. u. naturwiss. Unterricht*, **64**, 284–286, No. 6, 1933. A known quantity (about 25 liters) of the dry gas is aspirated through a coiled copper tube in a Dewar flask containing water at about 50°C, and the decrease in temperature is measured with an accurate thermometer. Another run with no gas passing through the tube gives the decrease in temperature due to radiation, conduction, etc., making it possible to calculate the amount of heat taken up by the gas and thus to calculate its specific heat at constant pressure. R. J. H.

INTERMEDIATE AND ADVANCED PHYSICS

14. Theory of probability. ALBERT A. BENNETT; *Elec. Eng.* **52**, 752–757, Nov., 1933. A brief outline of the history and of the present concepts of classical probability theory. D. R.

15. A complete analogy between electrical and mechanical vibrations. CARL RAMSAUER; *Phys. Zeits.* **34**, 459–461, June, 1933. Consider a system consisting of two identical spherical conductors, each of capacitance C, connected by a long straight wire at whose middle a coil of resistance R and self-inductance L is inserted. If the spheres be initially charged with quantities of electricity Q and $-Q$, so that their respective potentials are Φ and $-\Phi$, then it is easy to prove that the equation of motion of the system is

$$d^2\Phi/dt^2+(R/L)(d\Phi/dt)+2\Phi/LC=0.$$

Compare this system with a mechanical one which consists of two identical hollow spheres of large volume V, connected by a pipe of unit cross-sectional area and of negligible volume compared with V. In the middle of the pipe is a small fan whose axis of rotation passes symmetrically along the tube and through the spheres. At each end of this axis is attached a bar of moment of inertia $I/2$. When in equilibrium the system contains air at atmospheric pressure. If the one sphere initially contains an excess of air ΔA and is at a pressure ΔP above atmospheric, air will flow from the first sphere into the second, thus causing the fan to rotate and imparting energy to the inertia bars. Therefore, if there be no friction, the fan will continue to rotate until the pressure in the second sphere is ΔP above atmospheric. The system will then have completed half a vibration and the process continues. If it be assumed that the fan moves without slipping and that the speed of a point on an inertia bar unit distance from the axis is equal to that of the air in the pipe, it can be shown that the equation of motion of the system is

$$d^2(\Delta P)/dt^2+(\eta/I)\cdot(d(\Delta P)/dt)+2\Delta P/IV=0,$$

where η is the coefficient which represents the effect of air resistance. By comparing the two equations, one sees that there is a correspondence between Φ and ΔP, Q and ΔA, C and V, L and I, and R and η; hence the analogy is complete. D. R.

16. On the nature and the limitations of cosmical inquiries. P. W. BRIDGMAN; *Sci. Mo.* **37**, 385–397, Nov., 1933. The consequences concerning the possible nature of cosmical theories and the essential limitations to which the observational material is subject are set forth. G. A. V.

PHILOSOPHY OF SCIENCE

17. Causality in the physical world. R. B. LINDSAY; *Sci. Mo.* **37**, 330–337, Oct., 1933. "I think we may summarize by saying that there is such a thing as the principle of causality in physics and that it has played an important rôle in the building of the physical world. In this world and in this alone does strict causality in the physical sense reign. As soon as we try to make the transition from the physical world to that of our actual sense-perceptions, causality must be associated with the probability concept." G. A. V.